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13. ABSTRACT *(Maximum 200 words)*
Please find attached the slide report for the Nanosat program with the Emerald satellite, This is for the combined efforts of the Stanford and Santa Clara University Emerald Project.

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SCR EM!

SSDL

Nanosat One Critical Design Review

Principal Investigators:

Prof. Jonathan How

Prof. Christopher Kitts

Prof. Robert Twiggs

University Schedule

Emerald structures, mechanisms, and thermal Systems

- Program introduction
- Emerald/Orion common systems
- Emerald specific systems/experiments
- Orion specific systems/experiments

University Program Overview

- 3 satellites organized in 2 missions
- Orion Project
  - Stanford University
  - MIT
- Emerald Nanosatellite Project
  - Stanford University
  - Santa Clara University

Three Satellite Mission

- Formation Flying Concept
- Mission Description
- Mission Objectives
- Mission Profile
- Project Schedule

Formation Flying Concept

The small satellite advantage!

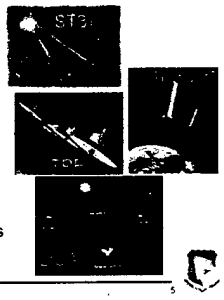
- Less costly
- Simpler designs
- New mission architectures

Clusters of cooperative satellites

Applications

- Synthetic apertures
- Distributed field measurements

Support from NASA & USAF



Formation Flying Concept

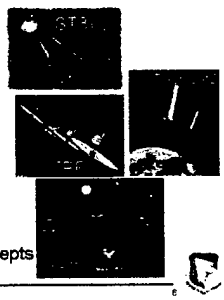
Challenges:

- Limited mission resources
- Fleet management & control
- Communication architecture

Methodology

Basic research Testbed missions

Verify principles Validate design concepts



Mission Description

Demonstrate closed-loop formation flying in space

Carrier phase GPS data shared

(Allows relative navigation & formation flying)

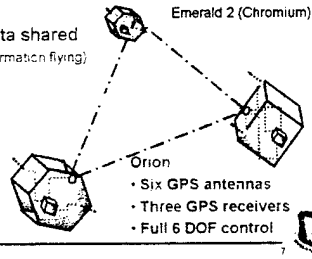
Emerald 2 (Chromium)

Emerald 1 (Beryl)

- Two GPS antennas
- One GPS receiver
- Limited control

Orion

- Six GPS antennas
- Three GPS receivers
- Full 6 DOF control

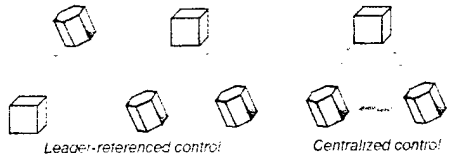


Mission Objectives

Comprehensive on-orbit demo of *true formation flying*

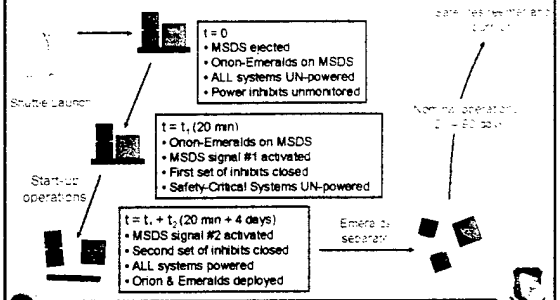
- Develop technologies to build a ***virtual spacecraft bus***
- GPS sensing & fleet control

Orion-Emerald system is a *flexible, low-cost* test platform



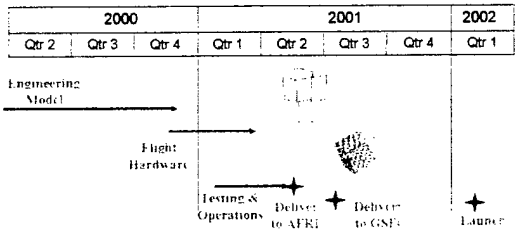
NASA GSFC 8

Mission Profile



NASA GSFC 9

Project Schedule



NASA GSFC 10

Orion Overview

- Development Team
- Mission/Experiments
- System Summary
- Requirements

NASA GSFC 11

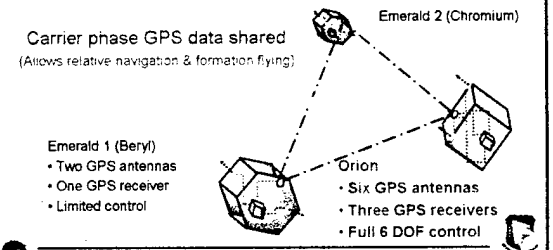
Orion Development Team

- Space Systems Development Lab
  - Dept. of Aeronautics and Astronautics, Stanford University
- Space Systems Laboratory
  - Dept. of Aeronautics and Astronautics, MIT
- http://ssdl.stanford.edu/orion

NASA GSFC 12

Orion Mission

Demonstrate closed-loop formation flying in space



NASA GSFC 13

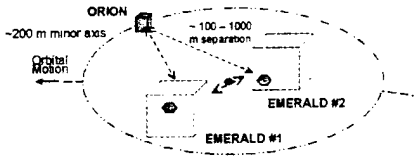
Experiments

PHASE 1: Orion in formation with 1 Emerald
- Emerald only performs GPS data collection & comm link
- Orion performs closed-loop control w.r.t. Emerald.
- Various (in-track) coarse, fine-parking, & precision modes
- At least 3 orbits, & repeatable over 2 weeks

PHASE 2: Orion in formation with 1 Emerald
- Emerald provides GPS data/comm link
- Emerald also responds to control inputs from Orion
- At least 3 orbits, & repeatable over 2 weeks.

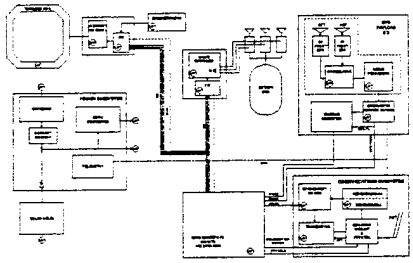
PHASE 3: Orion in formation with both Emeralds
- Same as phase 2, apply various control architectures
- At least 3 orbits, repeatable

Operational Details



- Align Emerald in-track positions as closely as possible
- Orion in closed-form relative motion with respect to the Emeralds' mean formation geometric center.
- Emeralds provide GPS data/comm link & respond to control inputs from Orion

System Concept



Orion Design Requirements

- Technical Goals
- Performance Requirements
- Safety Summary
- Integration

Technical Goals

- Demonstrate control for a cluster of micro-satellites.
  - real-time autonomous control software
  - formation directed at a high-level from the ground.
- Demonstrate GPS receiver for real-time attitude & relative navigation
  - first on-orbit demonstration of CDGPS for precise relative navigation and control
  - Expect <<1 m (relative - radial) for determination & 5 m (relative - radial) for control.
  - low-power, low-cost, attitude capable GPS receiver.
- Various control architectures and a real-time inter-vehicle communication link and ranging.

Performance Requirements

Mission success:

• Relative position determination	~10 cm
• Relative position control	~5 m
• Attitude determination	~2°
• Attitude control	~10°

Key design requirements:
- GPS receiver must function properly at all times
- Communications design must allow for direct data exchange between satellites during all phases
- Flight control software must control the constellation to the required degree of accuracy
- System resources must be sufficient to perform experiments as needed

Performance Requirements

General bus requirements:

- Mass and size restrictions as defined by MSDS budgets
- Components must operate within expected thermal environment
- Components must operate within expected radiation environment
- Component-level size, mass, and power restrictions

Performance Requirements

Subsystem requirement summary

Structure

- Provide structural support & mounting surfaces for all subsystem components
- Total system mass < [illegible] kg
- Structural fundamental frequency > [illegible] Hz
- Center of mass location within ¼" radius of geometric z-axis
- Survive launch loads
- Minimize changes to inertia matrix over time
- Fracture controls

Performance Requirements

GPS Payload

- Acquire and maintain GPS signal lock in all flight modes
- Sense satellite state (absolute & relative) to required mission levels
- Calculate satellite state at a sufficient rate to achieve necessary control bandwidth
- Calculate control responses at a sufficient rate

Power

- Supply enough current at appropriate voltage for all flight modes

Performance Requirements

Attitude Determination & Control

- Provide enough actuation authority for all flight modes in all expected environmental conditions
- Robustness against failure or poor performance
- Enough resources to ensure minimum mission success

Communications

- Provide reliable downlink and crosslink
- Utilize low-cost (amateur) transmission frequencies

Performance Requirements

Command & Data Handling

- Provide enough memory and processing speed to handle housekeeping tasks and routine data collection
- Provide serial interfaces to communications and GPS subsystems
- Provide PIC interface to ADCS and telemetry for distributed computing efficiency

Safety Summary - Structure

Issue	Hazard	Control
Strength	Structural failure due to insufficient design	Sine Burst Testing, FEM modeling
Natural Frequency	Dynamic coupling	Modal Testing, FEM Modeling
Acoustic	Structural failure during launch	Random Vibration Testing
Envelope	Interference with other payloads, ground support equipment etc.	Approved envelope compliance
Fracture Control	Structural failure due to flaws	Approved critical components and compliances
Manufacturing	Structural failure due to poor quality	Engineering Model, manufacture by procedure

Safety Summary - Propulsion

Issue	Hazard	Control
Components leak or rupture	Explosion, venting	Components meet/exceed required FOS Components tested to 1.5 x MDP System tested to 1.2 x MDP
Operational inhibits (Mechanical)	Inadvertent operations & associated hazards	2 fault tolerant design to prevent inadvertent venting of gas
Operational inhibits (Electrical)	Inadvertent operations & associated hazards	Latching relay inhibits on all subsystems with catastrophic hazards (x4)

Safety Summary - Power

Issue	Hazard	Control
Battery containment	Shorting, insecure positioning	Sealed T6061 Aluminum box
Battery leak or rupture	Fire, explosion, contamination, corrosion	Pressure relief valves with inline filters (20 psi crack pressure), (x2) Fiberglass absorbing material
Battery charging inhibits*	Overcharging hazards	Latching relay inhibits on solar cell-battery circuit path (x4)
Operational inhibits*	Inadvertent operations & associated hazards	Latching relay inhibits on all subsystems with catastrophic hazards (x4)

* Power inhibits are disabled when Orion receives a "safe distance" signal from the MSDS

Safety Summary – Torquer Coils

Issue	Hazard	Control
None	n/a	n/a

- No critical hazards exist
- Coil system is power inhibited with rest of main bus
- For inadvertent operation, analysis shows compliance with ICD 2-19001 section 10.7.3.2.1.2

Verification

- Measure the generated field strengths on flight article

Safety Summary

Comm

Issue	Hazard	Control
Inadvertent transmissions	Interference with Shuttle electronics	3-fault tolerant power inhibit scheme

CDH

Issue	Hazard	Control
Inadvertent operation of subsystems	Operation of hazardous subsytems	• 3-fault tolerant power inhibit scheme • Critical functions require confirmation • I2C commands require checksum

Integration Requirements

MSDS Integration

- Satellite must interface with MSDS deployment mechanism
- Satellite and all protrusions must fit within MSDS stack envelope

Ground Operations

- External port for battery charging
- Inhibit verification
- Operational testing
- Other servicing requirements

Emerald Overview

- Development Team
- Mission/Experiments
- System Summary
- Requirements

Development Team

- Stanford University
  - Graduate and undergraduate students
  - Master's and Ph.D. level
  - Volunteer time, work for course credit, Research Assistantships
- Santa Clara University
  - Undergraduate seniors
  - Senior design project credit
- http://ssdl.stanford.edu/emerald

Emerald Mission

Demonstrate Robust Distributed Space Systems

- A distributed architecture to facilitate integration and operations.
- Distributed and autonomous science experimentation and satellite operation
- Supporting subsystem-level technologies
- Simple closed-loop relative position control for 2 and 3 bodies (with Orion)
- Low-cost satellite development techniques

Development Approach

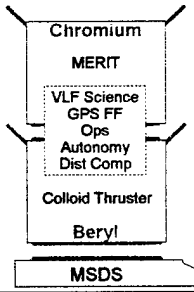
- Rapid prototyping: off-the-shelf components
- Building-block strategy
  - Start with minimized baseline design
  - Add features as time and funding allow
- Industry guidance and support
  - Mentors
  - Partnerships
- Aggressive schedule
- Internet distribution of information

Emerald Experiments

- GPS Formation Flying
- VLF Atmospheric Science

- Colloid Micro-Thruster
- Radiation Test Bed
- Experimental C&DH architecture

System Summary



- 19" hex, 9" x 12" sides
- Al honeycomb, stackable trays
- 12 v and 5 v reg. power
- I^2C data & command bus
- Dallas 1-Wire power switching & telemetry
- Half-duplex inter-satellite communication
- Full-duplex ground link
- Drag panel position control
- GPS relative positioning

Sources of Requirements

- Mission fulfillment
  - Experiment success
  - Operational integrity
- AFRL – for MSDS integration
- Launch safety considerations

Requirements Outline

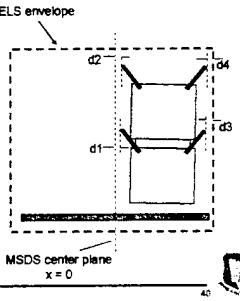
- Emerald Stack
- Subsystems
  - EPS
  - STRUCT/MECH
  - ADCS
  - COMM
  - CDH
- Experiments
  - VLF
  - CMT
  - MERIT
  - Formation Flying

Stack Requirements

- Mission success
  - Groundlink communication while stacked
  - Commandable separation
- AFRL integration
  - Envelope restrictions (RFDW)
  - < 50 kg
  - Natural frequency > 100 Hz

RFDW for Envelope Req.

- Comm antennas extend beyond AFRL envelope
- All clearances greater than .3 in. for SHELS static envelope



EPS Requirements

- Mission Success
  - Provide sufficient regulated power to nanosat systems througout mission life
- AFRL integration
  - Interface to MSDS electrical system for inhibit removal

EPS Requirements

- Launch Safety Requirements
  - Two fault tolerant inhibits on all power paths
  - Additional set of two fault tolerant inhibits on STRUCT/MECH subsystem (contact hazard)
  - Fourth inhibit used on each path to bypass inhibit monitoring requirement

STRUCT/MECH Requirements

- Mission Success
  - Provide structural stability and protection for all nanosat systems
  - Provide position control to enable formation flying – drag panels
  - Provide deployment of 3-meter VLF antenna
  - Provide ability to stack nanosats for launch
  - Provide ability to separate nanosats on-orbit

STRUCT/MECH Requirements

- AFRL integration requirements
  - Do not exceed envelope restrictions
  - Provide capability to mount to SSS
- Launch Safety Requirements
  - Structure and all mechanisms must adhere to NASA safety requirements

ADCS Requirements

- Mission Success
  - Determination
    - Measure spin rate within 1deg/sec (GPS and CMT)
    - Measure attitude within 5 deg (VLF)
  - Control
    - Spin rate to within 1 deg/sec in pitch and yaw (GPS)
    - Orient VLF antennas perpendicular to nadir within +/- 10 deg (VLF)

ADCS Requirements

- Launch Safety Requirement
  - Torquer coil magnetic field must be < -170 dBpT (~ 5 gauss) (we operate with ~ 1 gauss)

COMM Requirements

- Mission Success
  - Provide groundlink and inter-satellite communication
  - Provide low-power communication mode for crosslink
  - Provide sufficient bandwidth to downlink experimental data
- Launch Safety Requirement
  - RF emissions must not exceed levels specified in orbiter payload ICD

CDH Requirements

- Mission Success
  - Provide commanding and data handling capabilities for all nanosat systems throughout mission life
- No integration or safety requirements

Experiment Requirements

- No integration or safety requirements for:
  - VLF
  - MERIT
  - Formation Flying
  - Autonomy

Colloid Micro-Thruster (CMT)

- AFRL Integration Requirements
  - Accessible remove-before-flight covers
- Launch Safety Requirements
  - Propellant
    - Non-toxic
    - Non-corrosive
  - Protect ground crew from high-voltage (remove-before-flight covers)
  - Adhere to all NASA structural requirements for sealed containers

Command & Data Handling

Requirements

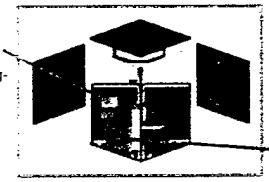
- Common system for Emerald and Orion
- Functional Requirements
  - Decode ground and inter-satellite communication
  - Forward commands to distributed subsystems
  - Coordinate/Control Experiments
  - Store/Buffer instrument data
  - Download data to the ground station
  - Control power switching for subsystems and experiments
  - Batch Commands and Scheduling for Operations
  - Gather health and telemetry data

Components: Emerald

- CPU (Spacequest)
  - Main command & data
  - Collect Health and Telemetry
  - Scheduling
- Data Bus (Dallas and I2C)
  - Modular connection to subsystems & experiments
- PIC Boards
  - Standard interface for subsystems to data bus
- Bus Monitor
  - Backup command & data
  - Operations Experiments

Components: Orion

Science computer
- Provides fast platform for floating-point calculations



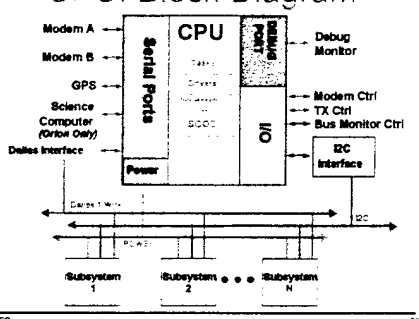
SpaceQuest CPU
- V53-based (10 MHz)
- 6 Serial Channels
- 1MB EDAC RAM
- BekTek OS (COTS)

PIC16F877 Subsystem Microcontrollers
- I2C Interface
- Serial
- 8 A/D Converters
- On-board RAM/ROM

CPU: Overview

- Processes Commands
  - Ground
  - Other Satellites
- Routes Information
  - Telemetry
- Scheduling and Experiment Coordination

CPU: Block Diagram



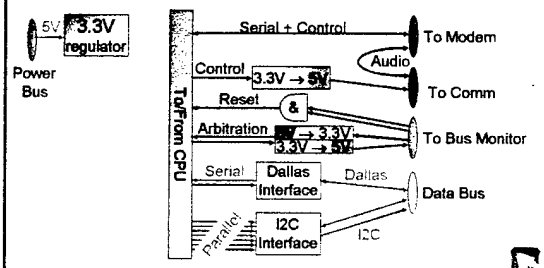
CPU: Motherboard

- SpaceQuest Rev C
  - NEC V53 processor
  - 10MHz Processor (1MIP
  - 1MB EDAC RAM
  - 6 Built-In serial channels
  - 40 Digital I/O channels
  - Built-In H/W for interface to S/W TNC

CPU: Adapter Board

- Purpose
  - Regulate 5V to 3.3V
  - Convert signals 5V ↔ 3.3V
  - House I2C Interface
  - Simplify Wiring Harness

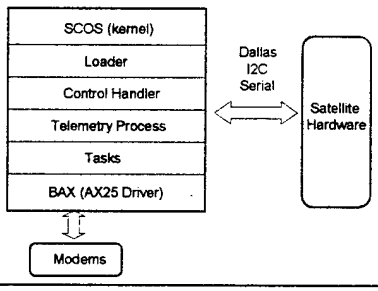
CPU: Adapter Board



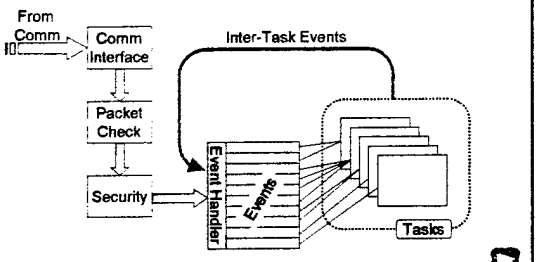
CPU: Operating System

- Space Craft Operating System (SCOS)
  - From BekTek
  - RAM-based file system
  - Multi-tasking and multi-user
  - Includes S/W for TNC using AX.25
  - Includes H/W and S/W Debugging Utilities
  - Software custom modified to in-house specifications

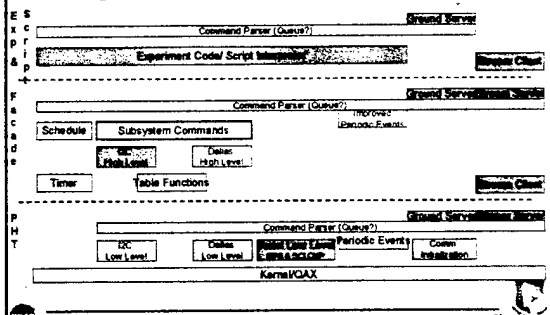
CPU: Software Architecture



CPU: Software Events



CPU: Software Hierarchy

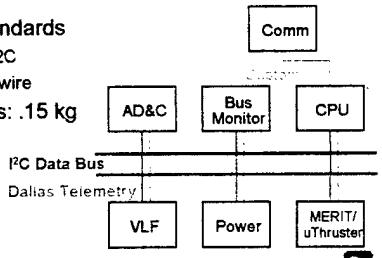


CPU: Serial Interface

- Dedicated Link to High Bandwidth Subsystems:
  - GPS
  - Science Computer (Orion Only)
- Signaling
  - TTL Level (+5V/0V)
  - RS232 Format
- Up to 57.6 kbps

Data Bus: Overview

- COTS Standards
  - Phillips I2C
  - Dallas 1-wire
- Total mass: .15 kg



Data Bus: Dallas

- COTS standard by Dallas Semiconductor
  - Asynchronous Serial Protocol
  - Can be powered through Data line
  - http://www.dalsemi.com/techbriefs/tb1.html
- Devices
  - DS18B20: Temperature Sensor
    - ±0.5°C Accuracy (-10°C to 85°C)
    - -55°C to +125°C Max Range
  - DS2450: 4 channel A to D
    - 8-bit resolution
    - Measure Voltages, Currents (with MAX471)
    - Can use at Open Drain Digital I/O

Data Bus: I2C

- COTS standard by Phillips Semiconductor
  - Synchronous Serial
  - 2 wires: Clock and Bi-directional Data
  - 100kbps signal rate (max)
  - Multi-master arbitration specified
  - http://www-us.semiconductors.com/i2c/
- Used for Command and Data
  - Subsystems and Experiments

Data Bus: I2C Extension

Packet Definition

Command Packet

From	Command (5 bytes)	Check

Data Packet

Size	Data (<126 bytes)	Check

Sequencing

Simple Command

Command	ACK

Command with Reply

Command	Reply	Data	ACK

Data Bus: Integrity

- Dallas
  - Separate Dallas 5V line
- I2C
  - Subsystems Isolated with Analog Switch
  - Dallas Power Control
  - Bus Monitor can reset CPU interface (Emerald only)

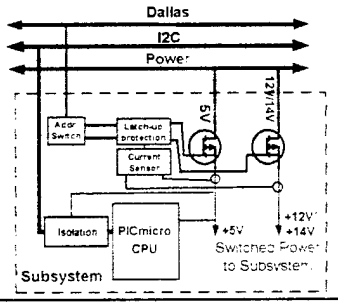
PIC Boards: Overview

- Standard interface board for all subsystems/experiments
  - Intelligent Subsystems/Experiments
  - I2C interface
  - Power switching
  - Standard Telemetry
  - 40-pin header connects subsystem hardware

PIC Boards: MicroController

- PIC16F877 (from MicroChip)
  - I2C Interface
  - Serial
  - 8 A to D Converters
  - On board RAM/ROM (limited)
- Standard Modules
  - I2C including Extension
  - Easy interface to PIC resources
  - 16KB Serial EEPROM (SPI)
  - Real Time Clock
  - 1.5MB SRAM (VLF and CMT)

PIC Boards: Power Interface



Manufacture

- Manufacturing
  - CPU board: manufactured by Space Quest Rev.C – CIC requested
  - PIC board: designed in-house, to be outsourced for printing and population - CIC requested
  - SCOS Operating System from BekTek – extensive testing in various projects - used in various space on missions
  - In-house Driver and Application software: modular structure and testing
  - CPU Adapter Board: designed in-house, to be outsourced for printing - CIC requested

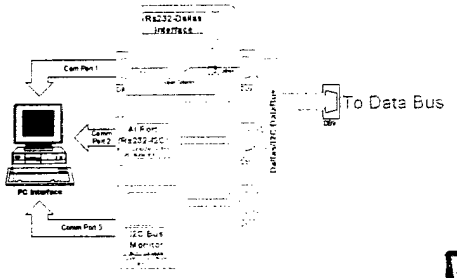
Testing: Overview

- Modular Design
  - Stand alone basic testing
  - Incremental Integration
- Bottom up testing
- Debug Interfaces
  - SpaceQuest CPU
  - PIC Boards

Testing: Equipment

- Artic Card (RIC) in PC
  - 80186 (V53 Compatable)
  - High level software testing
  - Modem/Serial interfacing
- PC to Data Bus interface
  - Dallas
  - I2C

Testing: PC – Data Bus interface

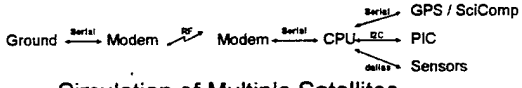


Testing: Interfaces

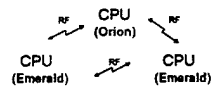
- ✓Dallas Send/Receive
- ✓I2C Send/Receive (extended)
- ✓Serial Send/Receive
- ✓Ax.25 Send/Receive (comm)
- Modem Control (digital I/O)
- Bus Monitor Arbitration (Emerald Only)

Testing: Full System

- Full Data Path



- Simulation of Multiple Satellites



Safety and Reliability

- Safety Compliance
  - C&DH subsystem powered off until safe distance from the Space Shuttle
  - All components conformal coated to minimize outgassing
- Reliability
  - Memory has 8 bit correctable EDAC
  - Critical functions require both command and confirmation
  - I2C commands require a valid checksum
  - Connectors are staked

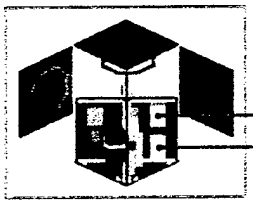
Communications

Requirements

- Common system for Emerald and Orion
- Functional Requirements
  - Satellite ↔ ground station
  - Satellite ↔ satellite
  - 9600 baud
  - Independent Download for Emerald vs. Orion
  - Receive only Frequency: No jamming

Components

- Full duplex up/down link, half-duplex cross-link
- 2W UHF power
- 350 mW X-L power
- Omni-directional antenna pattern, circular polarization



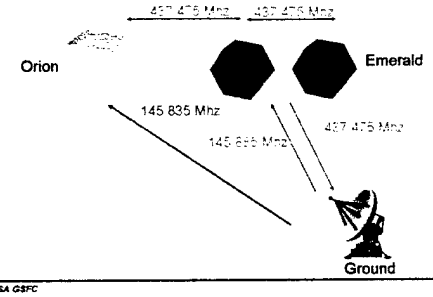
Hamtronics FM TX/RX kits

SpaceQuest GMSK modem
- AX.25 protocol, 9600 baud max data rate
- In-house assembly and test

Specifications

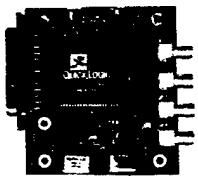
- Full Duplex, Mode J (amateur)
  - 2m Uplink
  - 70cm Downlink
- Half Duplex Crosslink (70cm)
- Omni-directional antennas with circular polarization.

Frequency Scheme



Modem

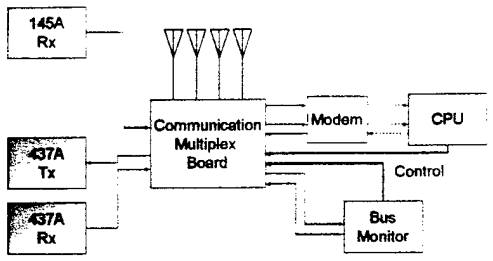
- Manufactured by SpaceQuest
- GMSK encoding
- Dual Channel
  1. 9600 baud fixed
  2. Software adjustable (9600 baud max)



Comm Multiplex Board

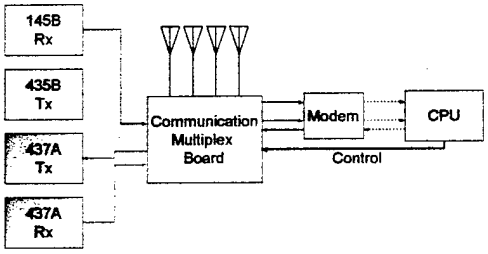
- Push-to-talk (PTT)
  - High Power (2W)
  - Low Power (350mW)
- Polarization Control
- Antenna Matching
- Supports fully Redundant system:
  - 2 Control/Signal Sources
  - 2 Transmitter/Reciever Pairs

Block Diagram: Emerald



Power Connections to Each Box omitted for clarity

Block Diagram: Orion



Power Connections to Each Box omitted for clarity

Manufacturing

- Radios: Hamtronics FM TX / RX kits modified for the space environment; In-house assembly and test*

*modifications: crystals, tantalum capacitors, removal of antenna amp in Rx

- Satellite modem: SpaceQuest GMSK modem – CIC requested
- Comm Multiplex Board: In-house design, assembly and test. Board manufacture: Advanced Circuits

Testing

- Component Testing
  - individual radio functionality/tuning
  - Modem configuration
  - Modem data transfer
  - Multiplex Board switching
- Interface Testing
  - CPU (and Bus Monitor)
  - Ground Station
- Incremental Testing (add links to middle of chain)
- Full System Test (see C&DH section)

Safety

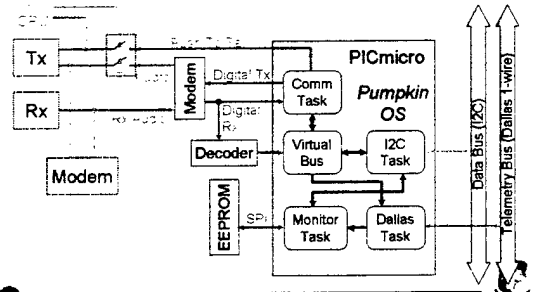
- Comm subsystem will be powered off until safe distance from the Space Shuttle
- Comm power supply inhibited by power subsystem (2 fault tolerant)
- All components will be conformal coated to minimize outgassing

Bus Monitor

Design Overview

- Monitors State and Activity of Data Bus
- Provides Direct Access to Data Bus
  - CPU Backup
  - Operations Experiments
- Can Achieve minimum functionality of all components on the Bus
- Separate Modem

Block Diagram



CPU Arbitration

- Comm interface board has hardware switch
  - CPU must send pulse to keep control
  - Tx, PTT, Power Level Control
- Direct CPU connection
  - Request Comm Control
  - Reset CPU's I2C interface
  - Reset CPU (requires 2 signals)

Performance

- I2C Master – 80 kbps (max)
- Dallas Master – ~1 kbps
- Modem Interface
  - 1200 baud
  - AFSK (Bell 202)
  - Half Duplex

Manufacture

- Manufacture
  - Manufactured by Advanced Circuits
  - Assembled by contractor
- Fabrication and assembly will adhere to published assembly instructions for all circuitry and hardware

Test

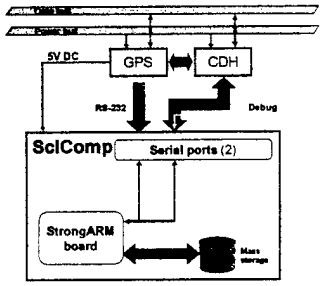
- Functional testing of all circuitry
- Communication Control Switching
- Communication Control Arbitration
- CPU's modem signal rejection
- RF ↔ Modem ↔ Bus Monitor ↔ PIC

Safety

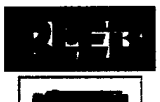
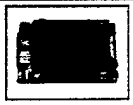
- C&DH subsystem powered off until safe distance from the Space Shuttle
- All components conformal coated to minimize outgassing
- CPU can prevent Bus Monitor control of Comm System

Science Computer

Functional Diagram



Hardware



VS

- StrongARM 1100 CPU
- Power: 2W
- Memory: 4 MB flash, 32 MB RAM
- Comm: 2xRS-232 (no handshake), 1xRS-422
- Limited Supply
- EM Development Purposes

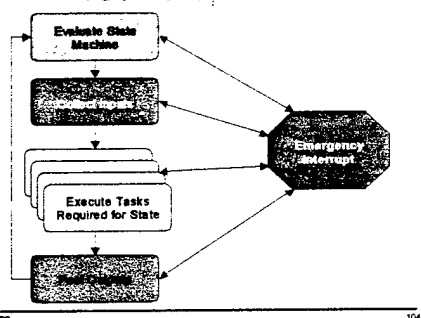
- StrongARM 1110 206MHz CPU
- Power: 2W
- Memory: 16 MB flash, 8-64 MB RAM
- Comm: 3xRS-232, GPIB
- COTS (two week delivery time)
- Proposed Flight Units

Software Development

- **ARM Linux**
  - Low Overhead
  - Low Cost
  - Versatile
- **Realtime Issues**
  - Realtime OS not needed
  - Low Bandwidth (< 10 Hz)
  - Write custom task dispatcher
- **PC Code Generation**
  - Translate Matlab M Functions into C
- **Linux Software Compilation**
  - GNU C Cross Compiler
  - Download Ramdisk into StrongArm

ARM

Task Dispatcher



NASA GSFC 104

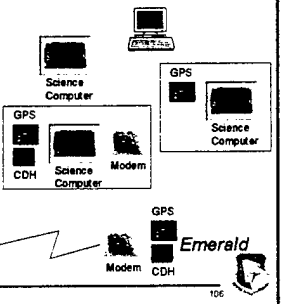
State Flow / Task Breakdown

Task	Shuttle Launch	Launch Plate	Wait for Separation	Stabilize Formation	Standby	Change Formation	Deorbit
GPS	☑	☑	☑	☑	☑		
Att. Ctrl			☑	☑	☑	☑	
Fuel Reg.			☑	☑	☑		
Estimation	☑	☑	☑	☑	☑		
Modeling	☑	☑	☑	☑	☑		
Form. Coord			☑	☑	☑		
Keep Alive	☑						

NASA GSFC 105

Verification and Test Plan

- Phase 1
  - Matlab Simulation
- Phase 2
  - Execute code Science Computer
- Phase 3
  - Connect GPS receiver boards to Science Computer
- Phase 4
  - Add CDH and modem
- Phase 5
  - Initiate communications with GPS/CDH/Modem cluster on Emerald



NASA GSFC 106

GPS Receiver

NASA GSFC 107

GPS Payload

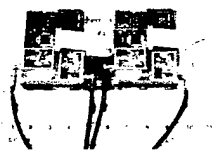
- GPS receiver
  - Power 8 W peak & 2 W "rest" mode
  - ~1kg & 12cm x 20cm x 25cm
  - 6 antennas (option for 8)
  - ARM60B and Strong ARM processors for navigation processing
  - Extensively tested on ground
- Based on Mitel Chipset
  - GP2015 RF front end
  - GP2021 12 channel correlator
  - Radiation tolerant
  - External clock linking micro-controller RF front ends

NASA GSFC 108

GPS Payload

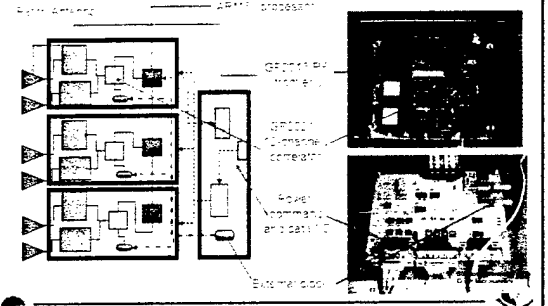
- Verification
  - Store and downlink raw GPS data to verify real-time solutions

Carrier-Phase GPS (CDGPS) provides a very accurate and cost effective means of performing relative navigation between spacecraft. The GPS receiver is the primary payload on the Orion spacecraft and one of the primary payloads on the Emerald nanosats. It is being cooperatively developed with NASA GSFC. Low-cost & very flexible design.



NASA GSFC 109

GPS Receiver Hardware



NASA GSFC 110

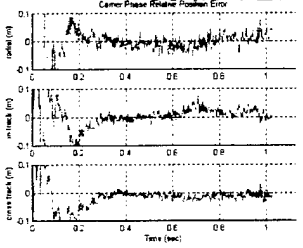
GPS Receiver Software

Features:

- Clock slews to synchronize with GPS time
  - Receivers on different vehicles still coordinated
- Improved Tracking Loops
  - FLL for acquisition, PLL for tracking
- Cycle Slip Detection
- Orbit propagator
  - Necessary for LEO initialization
- Relative orbit propagator and navigation algorithm

NASA GSFC 111

High Fidelity Sim: Position Error

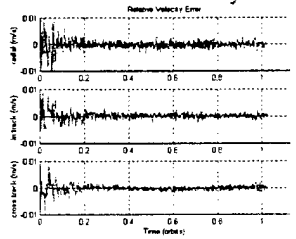


EKF solution of GPS measurements using truth file generated using GSFC Trajectory Determination System Simulation

$\sigma = 1\text{-}3$ cm

NASA GSFC 112

High Fidelity Sim: Velocity Error



EKF solution of GPS measurements using truth file generated using GSFC Trajectory Determination System Simulation

$\sigma = 1\text{-}2$ mm/sec

NASA GSFC 113

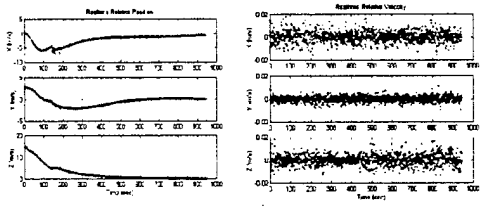
Predicted GPS Results

	μ	σ
Absolute Pos (m)	33.9	18.7
Relative Radial Position (cm)	1.3	3.22
Relative In-track Position (cm)	1.4	2.27
Relative Cross-track Position (cm)	1.6	1.45
Relative Radial Velocity (mm/s)	0.17	1.8
Relative In-track Velocity (mm/s)	0.26	1.1
Relative Z Velocity (mm/s)	0.14	1.0

- Matlab predicted estimation errors for realistic on-orbit scenario - includes bias acquisition.
- **Currently developing hardware in the loop tests to verify these results/assumptions**

NASA GSFC 114

Ground Test Results



Demonstration of real-time relative position and velocity estimate error using current modified receiver in ground-based test.

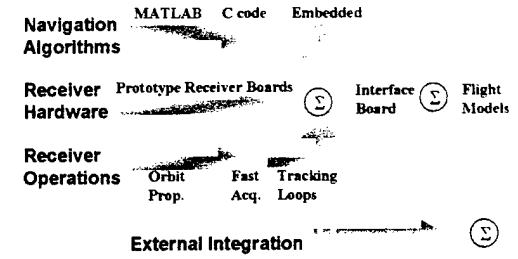
NASA GSFC 115

Manufacture and Test

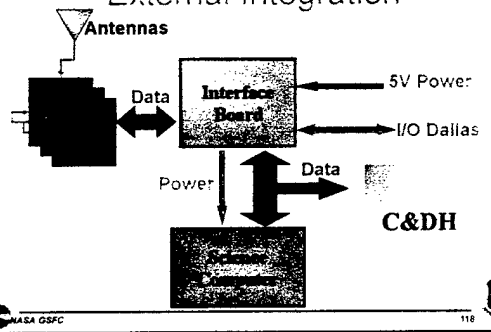
Milestones

- Hardware development
  - Prototype of GPS receiver and interface board complete
  - Complete integration
  - Minor mounting and shielding work
- Software development
  - Implement navigation and attitude algorithms previously developed in MATLAB in C
  - Run on ARM60 or Science Computer
- Test terrestrial performance
- Test using GSFC GNC GPS signal simulator
  - Use of simulator facility during development helped improve software design and will streamline testing

Development



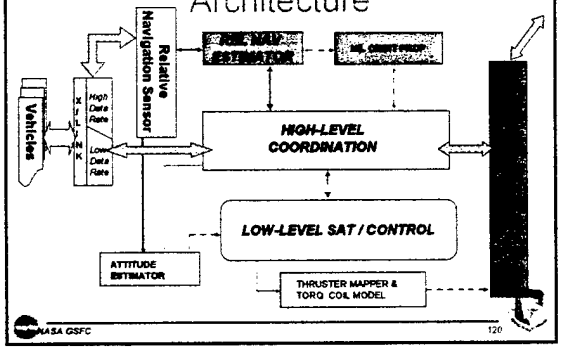
External Integration



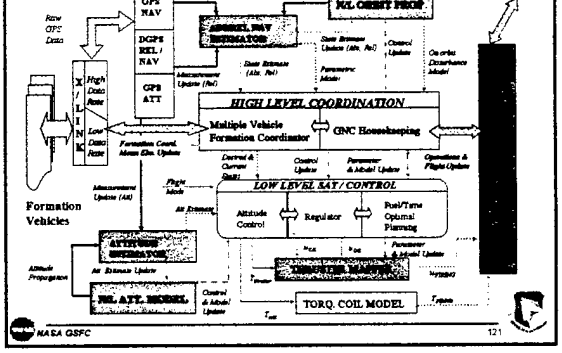
Control Features

- GPS receiver collects carrier, code, & Doppler measurements
  - Cross-links data to other formation vehicles
  - Inputs into estimator: absolute/relative navigation, attitude
- Absolute and relative estimators filter data with orbit propagators
  - Navigation estimate sent to high level formation coordinator
  - Attitude to low level vehicle controller
- High level coordinator commands all formation vehicles based on current operating mode

Architecture

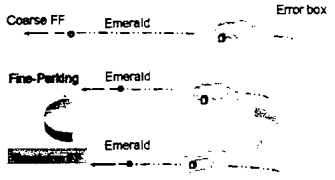


Formation Control Architecture

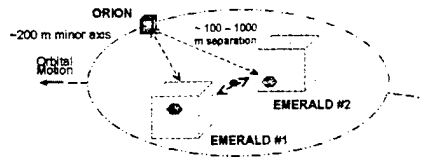


Operational Details

Experiment Modes	In-track Separation [m]	Relative Radial Tolerance [m]
Coarse FF	300	10-20
Fine Parking	100	10
Precision FF	100	2



Operational Details



- Align Emerald in-track positions as closely as possible
- Orion in closed-form relative motion with respect to the Emeralds' mean formation geometric center.
- Emeralds provide GPS data/comm link & respond to control inputs from Orion

Electrical Power Subsystem

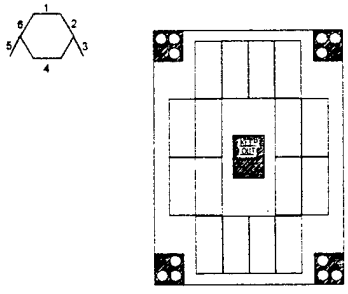
Design Summary

- Four Major Divisions
  - Body-mounted Gallium Arsenide solar cells
  - Electronics for power regulation, radiation latch-up protection, digital power switching, voltage, temperature and current measurement
  - One 10-cell, series-connected battery housed in 2 boxes of 5 cells each
  - Power inhibits

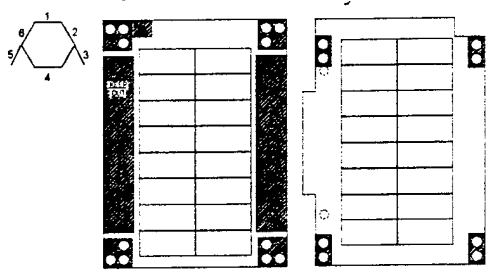
Body Mounted Solar Cells

- Spectrolab Gallium Arsenide triple-junction cells – 26% average efficiency
- Single cell voltage – 2.2 V open circuit
- 8 cells per string, 17.6 V open circuit
- 9.3 W average power
- 15 strings on each nanosat
- Kapton substrate electrically insulates cells from body panels

Panel 1 Layout



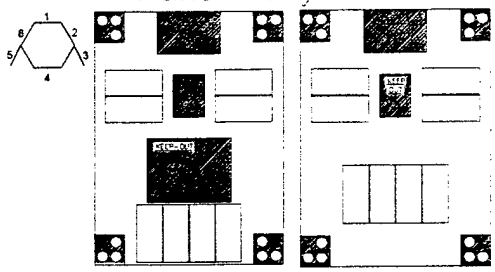
Panel 2/6/3/5 Layout



2/6 3/5

NASA GSFC 128

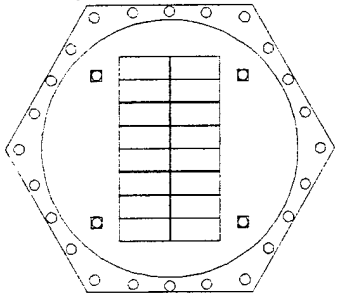
Panel 4 Layout



Beryl Chromium

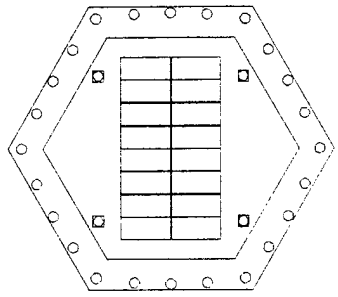
NASA GSFC 129

Beryl Bottom Layout



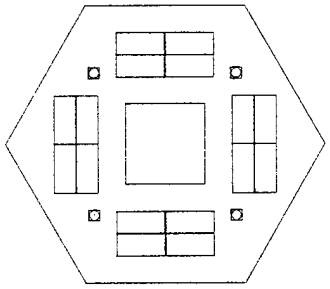
NASA GSFC 130

Intersatellite Layout



NASA GSFC 131

Chromium Top Hex Layout



NASA GSFC 132

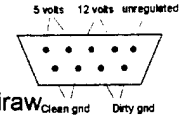
Electronics

- Vicor 5 and 12V power regulators
- 11 to 14V unregulated power
- Dallas 1-wire bus digital power switching
- Dallas DS1820 digital thermometers
- Maxim MAX471 current sensors
- Resistor network voltage sensors
- Dallas DS2450 A/D converters
- Latch-up protection at subsystem level
- .5 kg total mass of electronics

NASA GSFC 133

Power Distribution

- Dallas 1-Wire serial bus for Power Switching
- 3 distribution buses
  - –2 for general use
  - –1 for noisy/high power draw
- Standardized DB9 pin-out



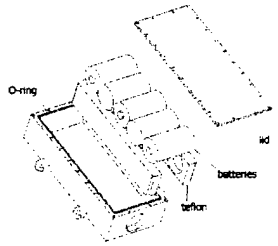
Battery

- One 10-cell, series-connected battery housed in 2 boxes of 5 cells each
- Sanyo CADNICA 5 AH KR-5000DEL cells
- Family of cells has flown on manned missions
- Each box is a sealed 6061 aluminum container
- 1.1 kg per box (including cells)

Battery Box

- 2 valves on "high" side of box
- Sub-micron filters to trap electrolyte
- Interior coated with non-conductive electrolyte resistant paint
- Positive terminals packed with electrolyte-absorbent material
- Purged with dry N2 to 20psia
- Teflon cell spacers
- Internal digital Temp./Press. sensors
- Viton O-ring to seal lid

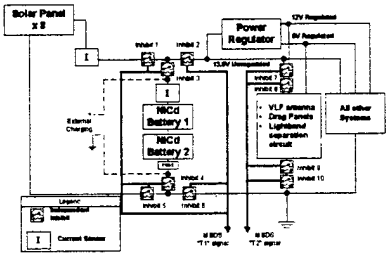
Battery Box



Power Inhibits

- Four inhibits in every current path to every subsystem
- At least 1 inhibit in every return leg
- 4 additional inhibits to STRUCH/MECH subsystem to inhibit operation of mechanisms
- Each inhibit is 2 aerospace-qualified, hermetically sealed relays in parallel

Power Inhibit Diagram



Power-Up Sequence

- Separation from Orbiter
  - All systems not powered
  - All inhibits not monitored
- T1 Signal from MSDS Platform
  - All systems powered except STRUCH/MECH
- T2 Signal from MSDS Platform
  - STRUCH/MECH system powered

Design Analysis

- Performance Analysis
  - Expected power output
- Structural Considerations
  - Battery Box
- Thermal Considerations
  - Batteries
  - Electronics

System Performance

Cell voltage	1.2	volts	Cell size	3.36	sq. in.
Cell capacity	5	AH	Cell current	264	mA
# of cells/pack	5	cell	Cell voltage	2.2	volts
# of packs	2	packs	S. Area to light	53.8	sq. in.
			Time illuminated/orbit	78.3	min.
[illegible]	[illegible]	volts/pack	Cell Power Output	580.8	mW
[illegible]	[illegible]	AH	Ce Pow Out/ S Area	173.85T	mW sq in
[illegible]	[illegible]	WH pack	Array Power Output	9299.714	mW
[illegible]	[illegible]	WH	Array energy out/orbit	12.198	WH

Battery Box Structural Analysis

- Must support mass of batteries
  - Battery mass, .75 kg per box
  - 20G dynamic load, 15 kg
  - 4 feet, .125 sq. in. area per foot
  - 66 psi total shear load on box feet
  - FS of 227 on foot strength
  - May reduce size of feet
- Must hold 20 psi internal pressure
  - .25 in. thick walls
  - FS of 10000
  - May reduce thickness of box walls

Thermal Analysis

- Battery the only critical component
- Battery thermal requirements
  - Charge
    - 0-45 deg. C.
  - Discharge
    - -20-60 deg. C.
  - Storage
    - -30-50 deg. C.
- Thermal finite element model shows compliance with these limits for on-orbit operation.

Battery Box Manufacture

- Materials
  - 6061 T6 Aluminum box structure
  - Teflon Battery Spacers
  - Fiberglass absorbant material
  - Vitron O-ring
  - 2 20 psi cracking check valves
  - Hermetic connector
- All parts of the EPS are non fracture critical

Battery Box Manufacture

- Construction
  - Boxes milled from aluminum
  - Spacers milled from Teflon
  - O-ring custom made
  - Check valves threaded into box
  - Hermetic connector threaded into box
  - Batteries set in spacers and potted

Electronics Manufacture

- Custom boards manufactured by Advanced Circuits and built at Stanford University
- Standard PicMicro board
- Fabrication and assembly will adhere to published assembly instructions for all circuitry and hardware

Test

- Battery Box
  - Proof test to 20 psi
  - Leak test (digital pressure sensor)
- System functional test

Ground Operations

- Battery box to be sealed and purged at the universities
- Inhibits disabled, reset, and verified through the STPI
  - Procedure will be listed here
- Batteries charged through the STPI
  - Procedure for charging will be here
  - 6 month time limit between charges, based on heritage experience with batteries from OPAL

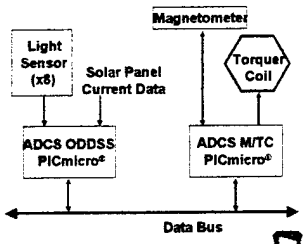
Requirements Fulfillment

- System meets power needs of spacecraft as designed
- Inhibit scheme adequately prevents power accidentally being applied

Attitude Determination and Control (ADCS)

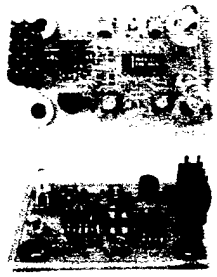
Design Summary

- Determination
  - Light Sensors
  - ODDSS
  - Magnetometer
- Control
  - Torquer Coil
  - Passive Drag



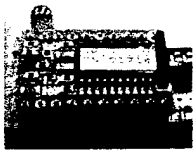
Attitude Determination

- Light Sensors
  - 2 sensors on each body panel
  - Each at 45° angle from body panel
  - On-board processing in ADCS ODDSS PICmicro®
  - Accuracy expected to meet subsystem requirements



Attitude Determination

- Magnetometer
  - Honeywell HMC2003 3-axis magnetometer
  - Range: +/- 40 µgauss to 2 gauss
  - Resolution: 40 µgauss
  - Output processed by ADCS M/TC PICmicro®

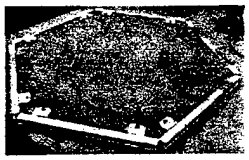


Attitude Determination

- Omni-Directional Differential Sun Sensing (ODDSS)
  - Algorithm developed for SAPPHIRE
  - Determines sun direction via solar panel currents
  - +/- 10 degree accuracy

Attitude Control

- Torquer Coil
  - Single coil oriented along stack axis
  - ~ 1 gauss field
  - Bi-directional



Attitude Control

- Passive drag orientation
  - VLF antenna provides torque sufficient to stabilize nanosat about pitch and yaw axes
  - Some rolling freedom is okay for requirements

Materials

- Light sensor, magnetometer, ODDSS
  - Electronic components
  - Custom-manufactured PCB
- Torquer Coil
  - Aluminum frame
  - Magnet wire
  - Epoxy: Stycast 2850FT w/ Catalyst 9

Mass & Fracture Control

- Mass
  - Electronics: 0.5 kg
  - Torquer Coil: 0.5 kg
- Fracture Control
  - No portions of the ADCS are fracture-critical

Design Analyses

- Analyses performed:
  - Separation analysis
  - Drag stabilization analysis
  - Torquer coil stabilization analysis

Separation Analysis

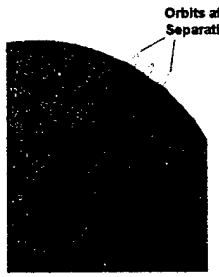
- Objective: determine optimal stack orientation for separation
- Goal: Separate stack such that resulting orbits are close together
- Examine two separation possibilities
  - In-track separation
  - Out-of-plane separation
  - Radial separation not feasible with available attitude control capabilitiy

Separation Analysis

- In-track separation
  - Can compensate for separation velocities using drag panels
  - If drag panels fail, satellites separate by ~250 km/day – only 10 hours of crosslink
  - If drag panels work, compensation takes ~20 days

Separation Analysis

- Out-of-plane separation
  - Causes inclination change – worst case 0.8 km
  - J2 perturbations add 3 km separation per month
  - Acceptable for mission success
  - Can achieve via torquer coil orientation & separation at northern- or southern-most part of orbit



Manufacture

- Custom boards manufactured by Advanced Circuits and built at Stanford University
- Standard PicMicro board
- Torquer coils constructed at Stanford University
- Fabrication and assembly will adhere to published assembly instructions for all circuitry and hardware

Test

- Functional testing performed on all circuitry and hardware

ADCS Ground Operations

- No ground operations required

Requirements Fulfillment

- Mission Success
  - The light sensors and magnetometer fulfill determination requirements
  - Passive drag stabilization meets operational requirements
  - Torquer coil stabilization allows optimal separation orientation
- Launch Safety Requirements
  - Torquer coil field well below limit

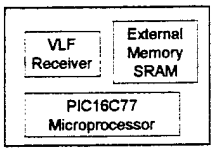
VLF Receiver Experiment

Experiment Objectives

- Mission Statement
  - This atmospheric science experiment utilizes a set of VLF receivers (one on each spacecraft) to detect electromagnetic disturbances due to lightning.
- Mission Objectives
  - Characterize the ionosphere
  - Validate benefits of formation flying
  - Perform a comparative study of how satellite size and processing architecture impact a baseline science mission

Design Summary

- VLF Reciever
  - Bandpass filter with peak amplification at 4KHZ
- PIC16C77 Microchip
  - 8K program memory
  - 20 MHz sampling speed
- External SRAM
  - Allows for an extra 1.0 M RAM
- Total mass .5 kg, including antenna



Operations

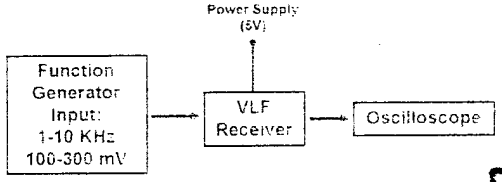
- Receiver Duties
  - Filter low frequency (1-10 kHz) EM disturbances
  - Amplify signal
    - Received wave 100-300 mV, Output wave 500-1000 mV
- PIC Processor duties
  - Sample VLF receiver data / store to PIC memory
  - Read PIC memory / send data across I2C Bus
  - Science data tagging
    - Time, attitude, absolute & relative positions

Manufacture

- Custom boards manufactured by Advanced Circuits and built at Stanford University
- Standard PicMicro board
- Fabrication and assembly will adhere to published assembly instructions for all circuitry and hardware

Test

- Functional testing of all circuitry



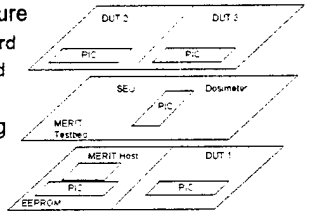
MERIT

Experiment Objectives

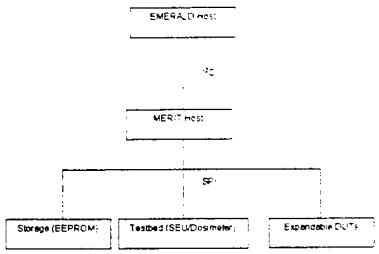
- MERIT: Micro Electronic Radiation In-flight Testbed
- Testbed for Measuring Effects of Radiation
- Modularity
  - Host
  - Device Under Test (DUT)
- Easy Expandability
  - Low power consumption
  - Small Size

Design Summary

- Modular architecture
  - Primary Host Board
  - SPI bus to testbed
  - SPI bus to DUTs
- Total mass: .65 kg



Hierarchy



MERIT Testbed

- Dosimetry Unit
  - Three 4007s (3 PFETs each)
  - Temp sensor for each 4007
- Single Event Upset Detector
  - Two 512kword SRAM
  - Three 4520s (sync. binary counter)
- 3 10 pin DUT headers
  - Supplies power and SPI signals

MERIT Host

- Communicates with Emerald Host via I2C
- Communicates with MERIT testbed and DUTs via Serial Peripheral Interface (SPI)
- Responsible for coordinating DUT testing and storing experimental data waiting for downlink

MERIT Operations

- Dosimeter
  - Test Mode (5% of time)
  - Accumulation Mode
- SEU Detector
  - Write 4 different bit patterns
  - Read Memory contents recording SEUs

Manufacture and Test

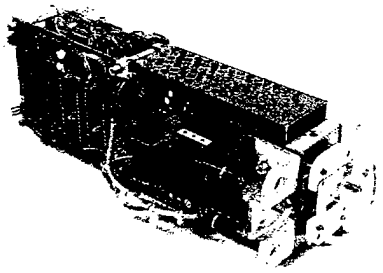
- Manufacture
  - Custom boards manufactured by Advanced Circuits and built at Stanford University
  - Standard PicMicro board
- Fabrication and assembly will adhere to published assembly instructions for all circuitry and hardware
- Test
  - Functional testing of all circuitry

Colloid Micro Thruster

Experiment Objectives

- Optimization of 70's technology into a Low-Power, High-Efficiency Micro-Thruster
  - Highly Integrated, Modular Design
  - New Thruster Core Design
- Technology Demonstration
  - Spacecraft Spin-Up to demonstrate operation
  - Thruster exhaust sensor to detect emission

CMT Prototype Rev 2.0



CMT System Revision

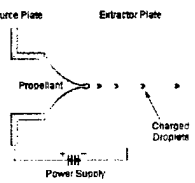
- Revision 1.0
  - Two Thruster Modules
  - Each Module has a Thruster Core and Propellant Systems

  Summary: One TCU, Two Modules, Two TCOREs, Two Propellant Systems
- Revision 2.0
  - One Thruster Module with two Thruster Cores
  - Both Thruster Core is fed by one Propellant System

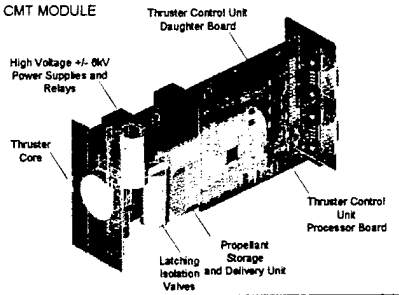
  Summary: One TCU, One Module, Two TCOREs, One Propellant System
    - Less hardware, less complexity
    - No impact to EMERALD / MSDS / SHELS or Shuttle Safety

CMT System Overview

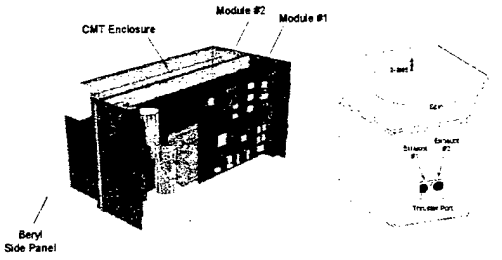
- Generate thrust by electrically charging and accelerating very small droplets
- One Thruster Module:
  - Two Different Thruster Core design is fed by One Propellant System
- Expected Performance:
  - 0.05 mN Thrust, ~500 sec Isp, 15 m/s ΔV
  - >90° satellite rotation after 15 min thrust
- Sodium-Iodide / Glycerol Propellant
  - 30 gr NaI per 100 ml Glycerol Solution
  - 20 milliliters, 25 grams, <1 psi pressure
- System Specification
  - 500 g system weight, 10 x 10 x 20 cm
  - 8 Watts max, no standby power
- Low-power, Hot-filament neutralizer



CMT System Overview



CMT System on Beryl



Cutaway of the CMT System

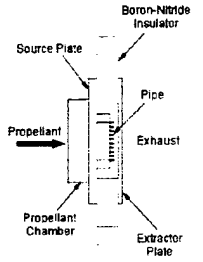
CMT on Beryl

CMT Thruster Control Unit

- Function of TCU:
  - Controls all CMT functions and communicates with the spacecraft main computer
- TCU Components
  - Digital logic:
    - PICmicro© 16F877 Microcontroller
    - Digital to Analog Converter
    - Analog Multiplexer
    - Random Access Memory for Data Storage
    - Picoammeter and Temperature Sensors
  - High-Voltage Power
    - +6kV and -6kV Power Supplies

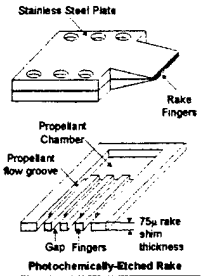
CMT Capillary Thruster Core

- Function of TCORE
  - Generate thrust using charged sub-micron particles
- Thruster Module #1
  - "Traditional" Design
- TCORE Components
  - Pipe Emitter
    - 150 μm OD / 50 μm ID
  - Source Plate (SS304)
  - Extractor Plate (SS304)
  - Insulator (Boron-Nitride)
  - Propellant Chamber (Teflon)



CMT Linear-Slit Thruster Core

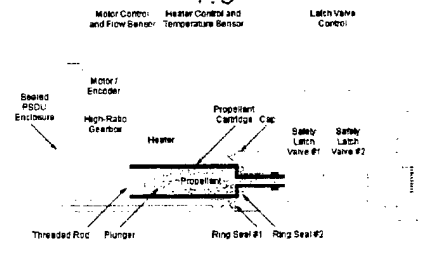
- Function of TCORE
  - Generate thrust using charged sub-micron particles
- Thruster Module #2
  - Manufacturing, Robustness advantage
- TCORE Components
  - Plate Source (Hardened SS)
    - Plate-Rake-Plate sandwich contruction
  - Extractor Plate (SS304)
  - Insulator (Teflon / BN)
  - Propellant Chamber (Teflon)



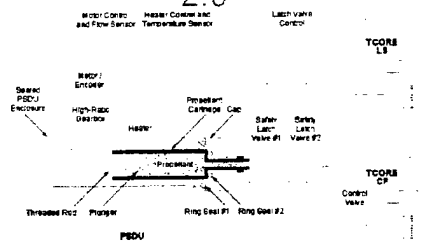
Propellant Storage & Delivery Unit

- Function of PSDU:
  - Propellant Storage
  - Supplies propellant to TCORE upon command from TCU
- PSDU Components
  - 10ml Propellant Cartridge
  - DC Motor w/ High-Ratio Gearbox
  - Threaded-Rod / Plunger Pumping Mechanism
- PSDU
  - Self-contained, sealed, battery-operated, medical-grade portable insulin pump
  - Modified to allow pump control by TCU
  - Modified to include a small heater

CMT Propellant System Rev 1.0



CMT Propellant System Rev 2.0



CMT Operation

- Ground Operation
  - Removal of Thruster Port Cover before integration into PLB
  - No other Ground Operation
- Flight Operation
  - Power will be available to CMT after T2 Signal from MSDS Platform

CMT Manufacture

- All hardware built, assembled and tested at Stanford University
- Complete manufacturing and fabrication documentation
- Functional testing performed in vacuum

CMT Test

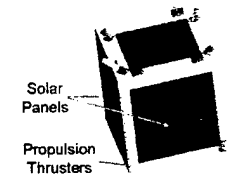
- Ground Experiments
  - Prototype accumulated ~30 hours of operation
  - Upcoming Direct Performance Measurement at Edwards AFB on micro-Newton thrust stand
- Performance Estimate
  - Capillary TCORE
    - ~0.01 mN Thrust, ~850 seconds Specific Impulse
  - Linear-Slit TCORE
    - TBD Thrust, TBD seconds Specific Impulse
- In addition to System Level tests with EMERALD:
  - Vibration, Vacuum, and Thermal Vacuum

Subsystems & Components Review

- Structure
- Propulsion
- Auxiliary Control
- Power
- Command & Data Handling
- Communications
- GPS Payload

Structure

Orion Exterior



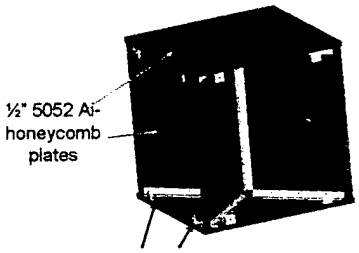
Mass Composition

Subsystem	Total Mass (g)
GPS Payload	1072
Structure	12403
CDH	900
Comm	696
Torquer Coils	2473
Propulsion System	10649
Power System	7140
Total	35332

Mass Limit = 40 kg
Mass Goal = 35 kg
Margin = 12%

Orion is within the mass budget

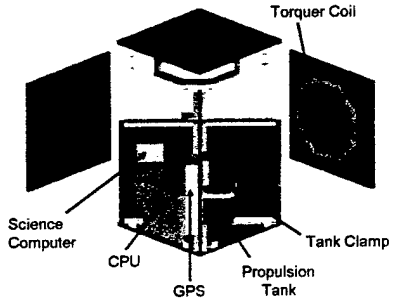
Orion Superstructure



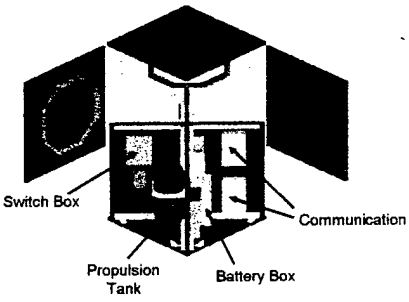
Features
- Simplicity
- Rigidity
- Symmetry

Dimension
- 17.5" cube
- 35 kg

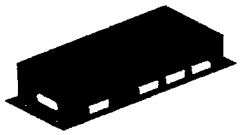
Orion Layout (View 1)



Orion Layout (View 2)



Component Box Design

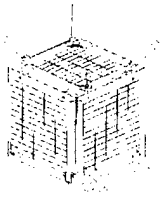


5052 AL Sheet metal

Circuit boards attach to box using #4 fasteners (high margin of safety application)

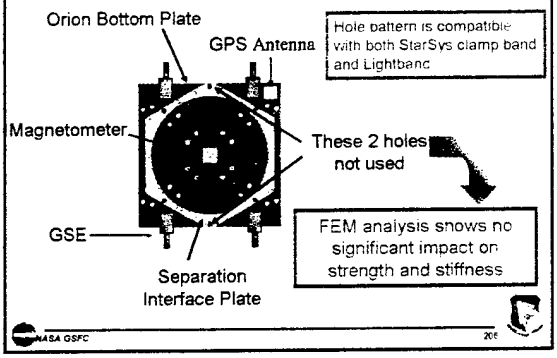
Box attaches to structure using #10 fasteners

Ground Support Equipment

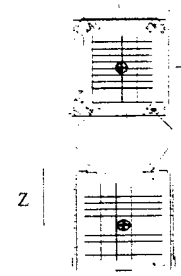


- GSE consists of 4 AL blocks that bolt to the bottom of Orion
- GSE extends 4 inches from the exterior of the structure
- Designed to withstand carrying loads
- Completely removable

Separation System Interface



CG Location



From the Geometric Center:

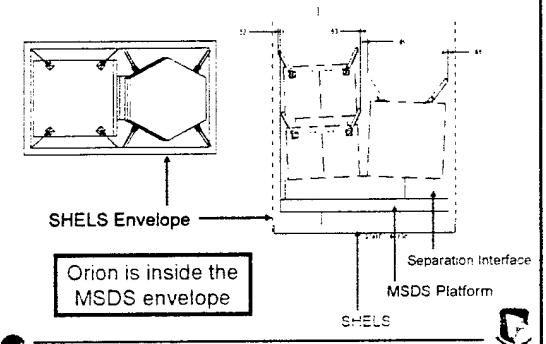
X = 0.035"

Y = -0.059"

Z = -0.7"

CG is within ¼" of the geometric z-axis

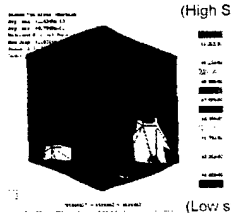
Envelope Requirement



Orion is inside the MSDS envelope

Finite Element Model

Design Test Load: 15.4 G's simultaneous in all axes (1.4 x design limit load)



Example Output

Results

- Natural frequency = 120 Hz
- 1st mode shape obtained
- Margin of Safety = 2.85

$$MS = \frac{AllowableStress}{FS * ActualStress} - 1$$

Modal Survey

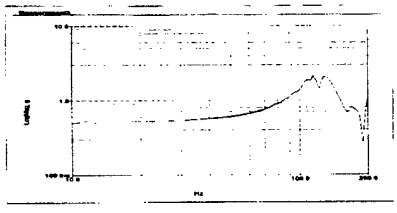
Orion mass model is securely bolted to an aluminum table.

Accelerometer is placed; Model is tapped with a hammer in the direction of interest.

Frequency data is acquired and processed.

Modal survey natural frequency = 125 Hz
FEM natural frequency = 120 Hz

Sine Sweep



Sine Sweep natural frequency = 120 Hz
FEM natural frequency = 120 Hz

- Structural frequency is above 100Hz
- FEM model verified

Fracture Control Overview

Component	Classification	Compliance
Al-honeycomb composite	Fracture critical	•Material Certification by AL composite supplier •Manufacturing consistent with established aerospace practices and done by written procedure •Pull testing of insert coupons consistent with flight articles •Sine burst testing at assembly level (1.2x design limit load)

Fracture Control Overview

Component	Classification	Compliance
6061-T6 Aluminum L Brackets	Low risk; non-fracture critical	• Table 1 material
Fasteners	Low risk; non-fracture critical	•#3,4 and 10 fasteners from GSFC •#3,#4 fasteners used in high Margin of Safety applications •All fasteners will have backoff prevention in the form of locking nuts, locking inserts or loctite •All stainless steel inserts will be screened for defects

Fracture Control Overview

Component	Classification	Compliance
Component boxes	Non fracture critical;contai ner	•Exempt
Battery box	Low-risk sealed container; non-fracture critical	•Aluminum Alloy •Proof Tested to 1.5 MDP (MDP = 32 psia)
Cold gas propulsion system: low pressure	Low risk; non-fracture critical; pressurized; fracture critical	•Will be covered later in the presentation
Cold gas propulsion system: high pressure		•Will be covered later in the presentation

Manufacturing Overview

Issue	Resolution
Flight Hardware Control	• Documented Inventory Control • Material Certification Documents
Integration Control	• Engineering Drawings of all components • Isolation of Flight Hardware • Manufactured in a Clean Room Environment at Stanford
Flight Qualification	• Strength: Sine Burst • Orient Assembly Procedure • Natural Frequency: Sine Sweep • Internal Verification Checklists • Vibroacoustic: Random

Flight Hardware Control

- Documented Inventory Control by means of inventory control forms provided by AFRL
  - All incoming flight materials will be accounted for in these documents
  - The forms will include purchasing information, quantities,dates, names, incoming inspection and other relevant information
- Isolation of Flight Hardware
  - All flight hardware will be kept in a clean environment and separate from all other

Integration Control

- Procedure Development
  - Assembly procedures for all components will be developed during engineering phase and will be used for flight instruction
  - The procedures will include instructions on assembly sequence, fasteners, torque specifications,handling and insert installation
- Engineering Drawings
  - All machined components have an associated engineering drawing
  - The drawings will be used to accurately manufacture the component to design

Integration Control

- Clean Room Environment
  - Flight Model components will be assembled in a clean environment at Stanford
- Internal Verification Checklists
  - A second person will observe and verify that the correct procedure is used to assemble flight components

Qualification

- Pull-testing of sample flight inserts
  - Random samples created for every flight composite panel
  - Samples will be tested and compared to known design strength characteristics
- Flight Strength Qualification by means of sine burst testing
  - Sine burst at 13.75 G's in each direction will be applied to the complete flight model
  - The flight model must survive without structural failure

Flight Qualification

- Natural frequency verification by sine sweep
  - Infinitely stiff interface will be assumed in this test
  - Accelerometers will be placed to capture the damped natural motion of the structure
  - The natural frequency of the entire structure must be above 100 Hz

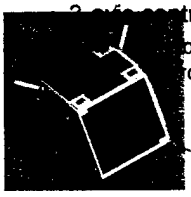
Requirements Summary

Issue	Requirement	Compliance
Strength	+/- 11G's all axes simultaneously	Sine Burst Testing, FEM modeling
Natural Frequency	100Hz minimum	Modal Testing, FEM Modeling
Acoustic	Survival of launch vibroacoustic environment	Random Vibration Testing
Mass, CG	Mass limit, CG within 0.25 inch from the geometric center	Mass ~35Kg CG within specification
Envelope	Orion envelope within the SHELS envelope.	Orion is well inside the boundary limits
Fracture Control	Prevent structural failure due to flaws	Approved critical components and [illegible]
Manufacturing	Prevent structural failure due to poor quality	[illegible] Model, manufacture by procedure

Propulsion

Design

A cold-gas propulsion system provides the required 6-DOF control required to meet mission maneuvering objectives

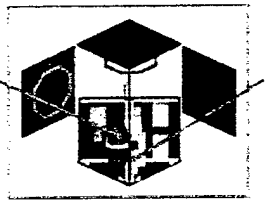


rol with 12 Thrusters
of 3 thruste[illegible]
ows)

Design

Cold Gas Propulsion

- Luxfer tanks
- GoRegulators
- Anger Scientific valves
- Quick-connect fill & drain port

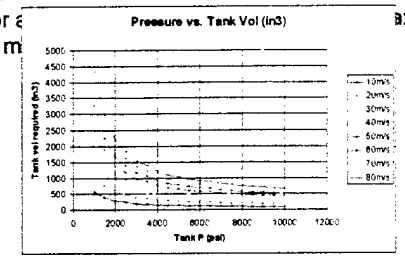


P/C valve control

- Propellant is GN2
- Total Delta-V ~ 25 m/s
- Isp ~ 60 sec. (measured)
- 60 mN thrust per thruster

Performance Analysis

- Preliminary analysis showed that min ΔV for one experiment is ~5 m/s
- For a [illegible] ax fuel → m



Performance Analysis

- Max P for tank determined by tank limits & NASA requirements
  - 1.5 x MDP < Proof (requirement)
  - Proof = 7500 psi → MDP < 5000 psi
  - MDP dictated by max Temp (100 deg. C)
  - At 20 deg. C, max Op P = 3500 psi
- Fuel capacity determined by max Op P
  - 0.5 kg per tank (x3)
  - 1.5 kg GN2 total

Design Parameters

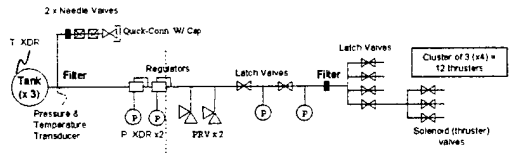
Maximum delta V within mass/volume budget ~26 m/s

- 3 cylindrical tanks
- High pressure (3,500 psia)
- Fuel : GN2

Budget constraints

- COTS parts
- Miniature valves and fittings
- In-house parts (low pressure side)
- Thruster manifold

Functional Design Summary



High Pressure	Low Pressure
Launch = 3500 psia	Launch = 50 psia
MOP = 3500 psia	MOP = 56 psia
MDP = 5000 psia	MDP = 75 psia

MDP values are based on conservative worst-case maximum temperature of 100 C

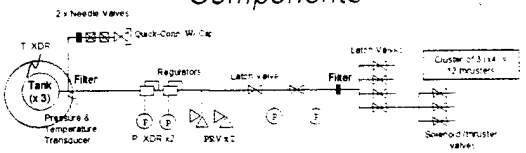
Mass Budget

Component	Mass (g)	amount	Total (kg)
Tank	1359	3	4.077
Regulator	325	2	0.65
Line Filters	274	2	0.548
Thruster Valve	24	12	0.288
Latching Valve	86	6	0.516
P, XDR (regs)	8	3	0.024
P, XDR (HP/LP)	10	3	0.03
Temp. Sensor	2	5	0.01
Plumbing	2000	1	2
Quick Connect	100	1	0.1
PRV	200	2	0.4
Manual Valves	500	2	1
Holders	75	3	0.225
Manifold	56	4	0.224
Nozzles	5	12	0.06
Electronics	1000	1	1
Fuel	1.5	1	0.0015
			11.2

Primary Materials List

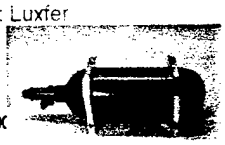
- Main Material
  - –Stainless Steel
  - –Aluminum
- Elastomers, Seals, O-rings
  - –PEEK
  - –Viton
  - –Teflon
  - –Tefzel

Components

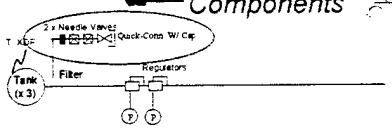


3 Cylindrical Tanks (Vendor: Luxfer Inc.)

- Carbon fiber wrapped
- Initial fill pressure 3500 psia
- Proof : 7500 psig, Burst : 15300
- Fuel: GN2

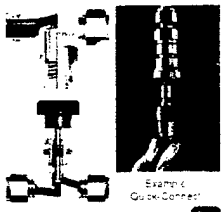


Components

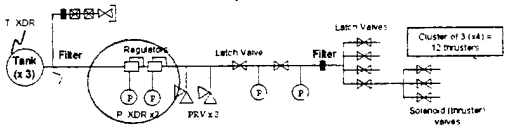


Service Port

- 2 manually operated needle valves
- 2-micron filter
- MOP rating of 6000 psig
- Proof : 12000 psig, Burst : 24000 psig
- 1 quick-connect (self-sealing)
- MOP rating of 10 ksig
- Proof : 20 ksig, Burst : 40 ksig
- Provide 2 fault tolerant mechanical inhibit from inadvertent release of GN2



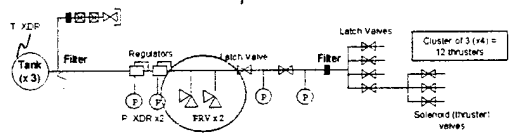
Components



Regulators (vendor: GoRegulators)

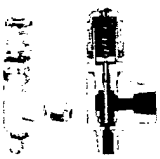
- 2 in series prevent high pressure from reaching low pressure side of system
- MOP rating of 6000 psig
- Proof : 12000 psig, Burst : 24000 psig
- Monitored using pressure transducer
- Tamper-proof handles (proprietary)

Components

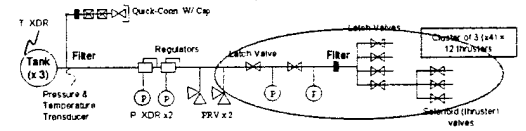


Pressure Relief Valves (vendor: Swagelok)

- Two in parallel prevent high pressure from over-pressurizing low pressure side of system
- MOP rating of 6000 psig
- Proof : 12000 psig, Burst : 24000 psig
- Setting preserved by lockwire
- Two PRVs required to relieve high-pressure "free-flow"



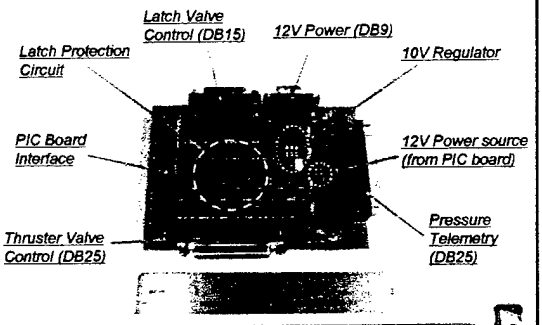
Components



Latch and Solenoid Valves (Angar Scientific)

- Electronically operated
- Provide 2 fault tolerant mechanical inhibit from inadvertent firing or leak
- MOP rating of 100 psig
- Proof : 250 psig, Burst : 500 psig
- 4 electrical inhibits prevent inadvertent operation

Electronics



Mechanical Safety Summary

Tanks : 5000 psi (MDP) x 1.5 (FOS) < 7500 psi Proof

High Pressure Side (MDP = 5000 psia)

Component	Burst (psia)	Comp FOS	FOS Req
Lines	30000	6	4
Regulator	24000	4.8	2.5
Sensor	15000	3	2.5
Transducer	30000	6	2.5
Filters	24000	4.8	2.5
Service valves	24000	4.8	2.5
Relief Valves	24000	4.8	2.5

FOS = factor of safety = Burst / MDP

Mechanical Safety Summary

Low Pressure Side (MDP = 75 psia)

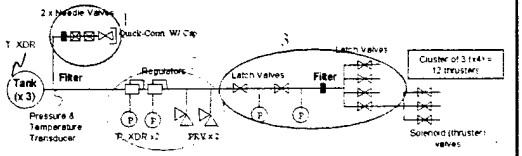
Component	Burst (psia)	Comp. FOS	FOS Req
Latch valves	500	7	2.5
Solenoid valves	500	7	2.5
Filters	24000	343	2.5
Transducers	600	9	2.5

FOS = factor of safety = Burst / MDP

Components meet or exceed all required factors of safety

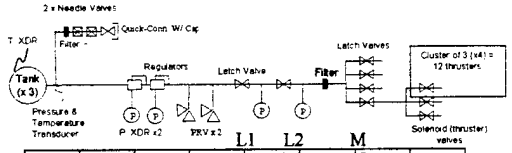
All components are leak-before-burst

Operational Safety Summary



1. **3 mechanical inhibits** prevent release of high pressure gas
2. **Two-fault tolerant control** prevents high-pressure gas from reaching low-pressure components
3. **3 mechanical inhibits** prevent release of low pressure gas

Closure Procedure



Steps	L1 status	P reading (L1-L2)	L2 status	P reading (L2-M)	M status	Pressure state (no	Thruster
			L1	L2	M		
1	Open	H	Open	H	Open	H	Closed
2	Closed	H	Closed	H	Closed	A	Open
3	Closed	H	Closed	H	Closed	A	Closed
4	Closed	M	Open	M	Open	M	Closed
5	Closed	M	Closed	M	Closed	A	Open
6	Closed	M	Closed	L	Open	L	Closed
7	Closed	M	Closed	L	Closed	A	Open

H : higher P (50 psia) M : medium P (~40 psia) L : low P (~30 psia) A : ambient (~15 psia)

Certification

- Luxfer Gas Cylinders L17C
  - Seamless aluminum wrapped with carbon fiber
- Classified as fracture critical
  - Tanks are leak-before-burst
  - Tanks meet DOT-CFFC
    - documentation supplied by manufacturer
  - Manufactured using standard aerospace industry practices
    - Flown on satellite operations and shuttle missions

Tank Thermal Analysis

Analysis results:

- Starting condition of 100 C
- Worst-case heating (sun on top panel, earth on bottom)
- Radiation heat transfer only from propellant tanks

LM ATC IDEAS/TMG Model

Results after 20 minutes deployment

Manufacturing

- Assembly done in clean environment
  - Class 10000 clean room for construction
  - Parts stored in "clean box" (inside clean room)
- Assembly Plan
  - Assemble main propulsion building blocks in clean room
    - Thruster clusters : thruster valves, fittings, manifold, and nozzles
    - Regulator cluster : regulators, pressure transducers on "baseplate"
    - Latch valve clusters : fittings, pressure transducers on "baseplate"
    - Service port : manual valves, fittings, and quick-connect
  - Integrate into structure in clean room
    - Tanks are placed and connected to service port
    - Integration of "baseplates" onto structure

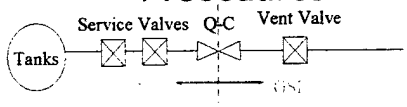
Performance Testing

- Nozzle tested using vacuum chamber
  - Each flight nozzle is fired directly upward; firing duration is minimized to reduce pressure effect on test apparatus
  - Spring/mass system records thrust
  - Mass flow recorded, Isp calculated
- Current results closely match the theoretical values
- All flight nozzles tested to ensure consistent quality
- All electronic systems (valves, sensors, and PIC) checked for correct operation
  - Thrusters will be actuated randomly to check for

Testing

- Proof Testing required for flight
  - Tanks are qualified as per MIL-STD-1522A "Path C" (reference : Figure 2, p. 28)
  - Hydrostatic testing
    - System cycled twice at 1.5 x MOP
  - Visual inspection, leak test
- Functional
  - Valve actuation
  - Leak test

Ground Ops Procedures



- Filling Prop system
  - Mate Quick-Connect
  - Open service valves
  - Start GN2 flow
  - Fill tanks
  - Close both service valves
  - Stop GN2 flow
  - Open vent valve
  - Disconnect Q-C

Requirements Summary

Issue	Requirement	Compliance
Attitude control	Perform required maneuver	Test functions of 12 thrusters
Attitude control	3-axis control	Test 12 thrusters required for 3-axis
Fracture control	All components meet and exceed safety factor	Select components that exceed FOS Parts are Leak Before Burst
Inhibits	Mechanical inhibits/controls and	Provide and verify required inhibits
Vibration/Load	Survival with vibroacoustic environment	Shake Test

Auxiliary Control

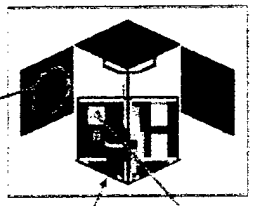
Requirements

Orion main ADCS requires [illegible] and GPS system without a GPS signal [illegible] control is required

- Primary Function
  - Detumble Orion from initial tip-off after deployment or satellite reset events
    - Total spin rate less than 0.7 rad/min (0.67 deg/sec)
  - Overcome any environmental disturbance torques (primarily aerodynamic disturbances)

Design

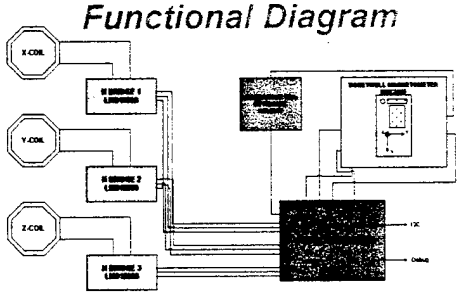
Torque coils (auxiliary control)



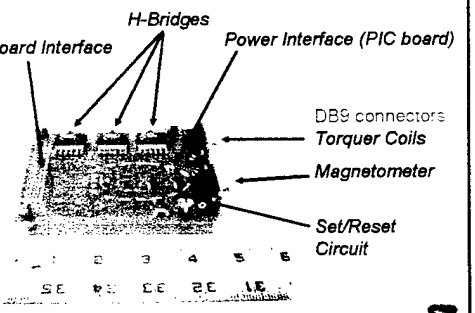
- Diameter = 13.25 in
- Enclosed Area = 145.7 in²
- AWG 28 Copper Wire
  - 550 Turns, 137 Ohms
- Mass = 700 g/coil
- Nominal Current = 100 mA
- Dipole Moment = 5.1 A-m²
- B-field Strength = 1.6 Gauss

- PIC microcontroller runs control algorithm
- [illegible] under bottom panel
- Honeywell HMC2003 magnetometer
- Dipole moment ~5 Am

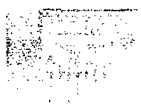
Functional Diagram



Electronics Board



LMD18200 H-bridge



National Semiconductor LMD18200 (1 per coil)

- Operating Voltage: +12V to +55V
- Operating temperature:-40 to +125 C
- 3A maximum continuous output capability (6A peak output)
- 3 logic inputs per H-bridge

Logic inputs will be used to [illegible] the torquer coils

Honeywell HMR2300 Magnetometer

- 3-axis magnetic field measurements
- Magneto-resistive permalloy sensor
- 40uGauss resolution
- Field range: -2 to +2 Gauss
- Supply voltage: +6 to +15V
- Maximum supply current: 20mA
- Operating temperature: -55 to +125 C

1 2

Set/Reset Circuit

- Eliminates effect of past magnetic history
- Momentarily magnetize (momentarily flip polarity)
- Higher resolution and maximize sensitivity
- Corrects for temperature drifts

Materials Summary

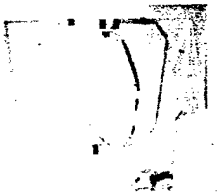
Coil Assembly
Aluminum U-channel: AL-6061
Insulated Magnet Wire: C11100 (AWG28) - NEMA 1000 MW-73/35, UL
Epoxy: Stycast 2850FT with Catalist 9
Electronics - PIC Board
Board: FR4
Copper
Surface Mount ICs
DB9 Connectors: Mil-c-24308
Electronics - Subsystem Control Board
Board: FR4
Copper
Surface Mount ICs
DB9 Connectors: Mil-c-24308
H-Bridge
Magnetometer

Mass Budget

Major Component	Quantity	Mass per Item (g)	Total Mass (g)
Wire Coil	3	666	1998
Epoxy	3	100	300
PIC daugher board	1	65	65
PIC mother board	1	100	100
Magnetometer	1	10	10
Total Subsystem			2473

Coil Performance

- Mass/pulley balance setup
- Estimate amount of torque produced by the coils



- Higher current supplied to create measurable torques
- Test results:
  - Analysis: 3.54mN-m
  - Experiment: 3.64mN-m

Control Law

Minus K-Bdot Law: Earth's Magnetic Field

$$\mathbf{M} = -k(d\mathbf{B}/dt)$$

Control Gain

Time rate of change of the magnetic field in the body frame

Control torque $T = \vec{M} \times \vec{B}$

- Coils can either can be **ON** (in two directions) or **OFF**
- Vary the torque produced by the coils in a "time-averaged" sense

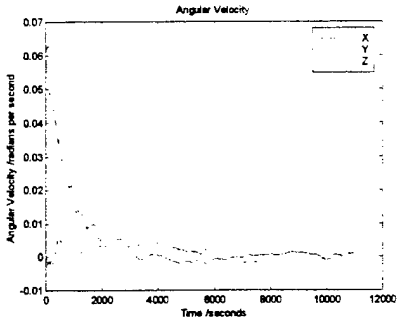
Attitude Simulation

- Integrated Attitude Simulation
  - Full nonlinear attitude simulation
  - Works in conjunction with our orbit and station-keeping simulations
  - Includes aerodynamic drag and residual dipole disturbances
  - Verified with several known test cases
- Realistic testing of controllers
  - Torquer coil & magnetometers

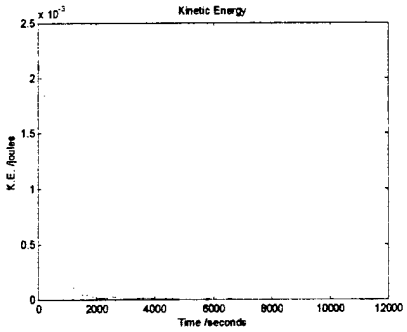
Attitude Simulation

- Simulation Results
  - Angular velocity reduced to less than 0.67°/second: within operating limits
  - Works in the presence of aerodynamic drag torque
- Test Case Shown
  - High initial angular velocity
  - Spin has component in magnetic field axis

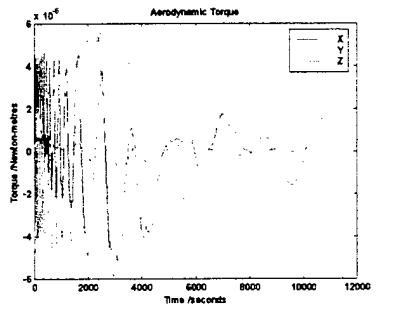
Simulation Results 1



Simulation Results 2



Simulation Results 3



Torquer Coils Manufacturing

- Aluminum frame construction
  - Clean unbent aluminum channel and inspect for defects (notches, dents, etc.)
  - Cut frame at specific bending locations (corresponding with octagon shape)
    - –7 cuts total, vertical sections of U-channel only
  - Bend U-channel into octagon shape and attach free ends with epoxy
    - –Sand down and smooth cut surfaces and any rough edges
  - Clean completed aluminum frame of all loose materials
- Attach mounting brackets to aluminum frame
  - Manufacture four brackets per frame by cutting L-channel into small sections
  - Grind down and smooth edges
  - Match drill holes through frames and brackets for precise fit and placement
  - Bolt brackets onto the frames

Torquer Coils Manufacturing

- Aluminum frame electrical insulation
  - Combine epoxy and catalyst (STYCAST 2850FT with CATALYST 9: Material Code 05257)
  - Apply a thin layer on the inner surface of the frame
  - After curing, inspect that there are no voids in the coating
- Copper windings
  - Wrap the aluminum frames with AWG28 magnet wire
  - Care must be taken not to the damage the insulation-coating on the wire by accidental abrasion against the frame's corners and edges

Control Board Manufacturing

- The Printed Circuit Board (PCB) of the Control Board will be manufactured by Advanced Circuits, Inc. according to our design
- Populating the PCB
  - Each component will be soldered in place one-by-one in an orderly fashion following the board design layout

Magnetometer Board

- The Magnetometer PCB will be manufactured by Advanced Circuits, Inc. according to our design
- Populating the PCB
  - The magnetic sensor will be soldered onto the board and the connections will be visually and electronically inspected.

Testing & Integration

Torqer Coils

- During the coil winding process check for electrical shorts between wires and frame every 100 turns
  - Ensure even spacing of windings
- Measure the B-field generated by the coils using the magnetometer
  - Place magnetometer in the center of the coil and gather data
  - Compare with design value
- Interface with the Control Board and test each coil
  - Monitor the H-bridge telemetry data (current output) and verify proper operation of each coil
- Mount each coil on the interior of Orion's panels
  - Test for electrical shorts between the coil assembly and panels
  - Make sure coils are properly fastened in place

Testing & Integration

Control Board

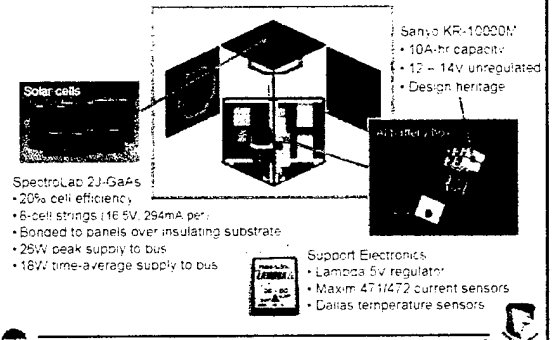
- Connection continuity tests during board populating procedure
- Board circuitry testing of:
  - Magnetometer Set/Reset circuit
    - Visually confirm proper pulse signals using an oscilloscope
  - Magnetometer ON/OFF control circuit
  - H-bridge operation
- Interface with PIC board and validate board functionality
  - PIC code operations
- Integrate PIC board/Control Board with Power Bus
  - Confirm that enough power is supplied for full subsystem operations

Requirements Summary

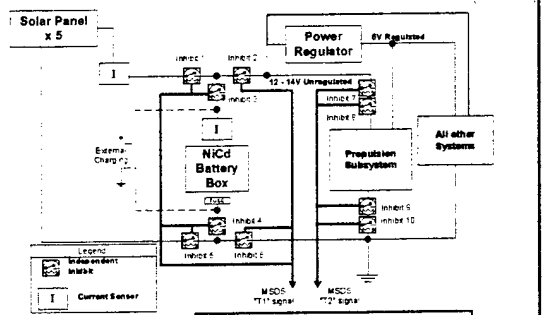
Issue	Requirement	Compliance
Torque	Provide enough to overcome any anticipated disturbance torques and detumble Orion	Measure generated magnetic field and compare with EM data
Control Algorithm	Vary acutation time and direction of dipole moment depending on measured B-field	EM PIC code development and testing
Control Algorithm	Detumble Orion down to 0.7 rad/sec	Simulation results
Maximum B-field	Must be below strength specified in the Shuttle Orbiter/Cargo Standard Interfaces Document ICD 2-19001 Rev. L (	Current design, as measured using a magnetometer is below 170 dBpT at

Orion Power

Design

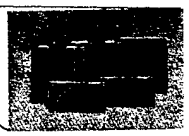


Wiring Diagram

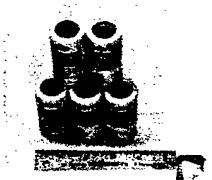


18-gauge strand-wire power bus

Component Selection



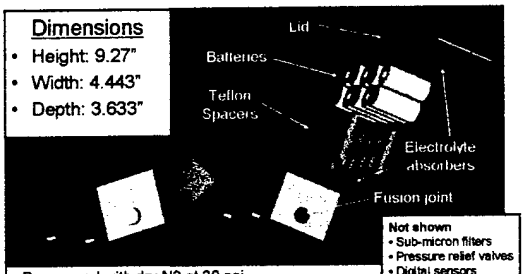
SpectroLab 2J-GaAs
- 20% Cell efficiency
- 8-cell strings (16.5V, 294mA)
- Bonded to side panels over insulating substrate



Sanyo KR-10000M
- One pack, 10 cells (10A-hr capacity)
- 12 to 14V unregulated
- Design heritage

Aluminum Battery Box

Dimensions
- Height: 9.27"
- Width: 4.443"
- Depth: 3.633"



Not shown
- Sub-micron filters
- Pressure relief valves
- Digital sensors
- Viton O-ring

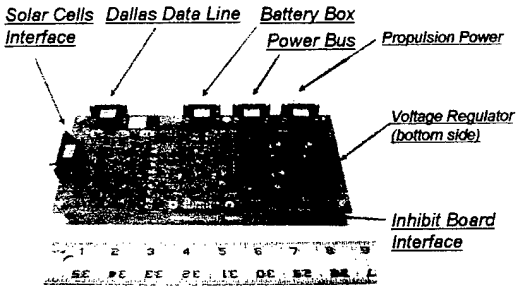
- Box purged with dry N2 at 20 psi
- Absorbent material prevents electrolyte leakage
- Internal non-conductive, electrolyte-resistant coating

Component Selection

Support Electronics
- Maxim 471/472 current sensors
- Dallas temperature sensors
- Leach Electronics DPDT latching relays

Lambda PM30-12S05
- 8-12V input → 5V output
- 30W max output

Electronics Board



Materials Summary

Power Bus
Electrical Wiring
DB9, DB15, DB25 Connectors: Mil-c-24308
Electronics - Printed Circuit Board
Board: FR4
Copper
Surface Mount ICs
DB9, DB15 Connectors: Mil-c-24308
Batteries
Nickel Cadmium
Battery Box
Aluminum 6061
Fiberglass
Teflon
Solar Cells
Gallium Arsenide
Glass

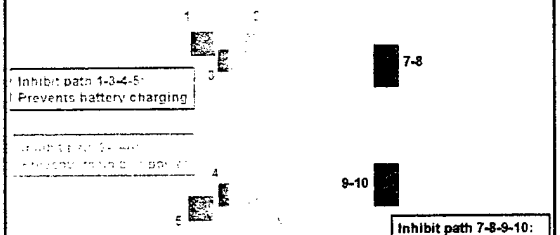
Mass Budget

Major Component	Quantity	Mass per Item (g)	Total Mass (g)
NiCd Batteries	10	400	4000
Battery Box	1	2000	2000
Electronics	1	100	100
DC/DC Converter	1	65	65
Wiring Harness	1	100	100
Solar Cells	250	3.5	875
Total Subsystem			7140

Telemetry

- Temperature Probes
  - Behind each panel (all six sides of Orion body)
  - Three on NiCd battery pack
  - One on DC-DC converter
- Current Sensor
  - After each solar cell panel (magnitude only)
  - Current magnitude and direction for battery pack

Inhibit Paths



Power Budget

Subsystem	Total Mass (g)	Power: Startup (mW)	Power: Cruise (mW)	Power: Contact (mW)	Power: Exper (mW)
GPS Payload	1072	1450	1450	1450	5225
Structure	8704	0	0	0	0
CDH	965	698	698	698	7198
Comm	696	1426	1426	5890	2376
Torquer Coils	2083	3740	250	250	250
Propulsion System	12044	300	300	300	22380
Power System	5140	0	0	0	0
Total	31704	7614	4124	8588	37429
Budget/Allocation	30000	8600	9600	25100	24600
Margin	-5.7%	11.5%	57.0%	65.8%	-52.2%
5V Current Draw (mA)		636	586	586	2431
12V Current Draw (mA)		333	108	348	2068
Total System Draw (mA)	Voltage -->	800	354	594	3089

Design Analysis

Structural Design Trade-off worksheet

Outer Panel Width	42.5	cm
Outer Panel Height	43.2	cm
String Current	294	mA

Solar panel sizing

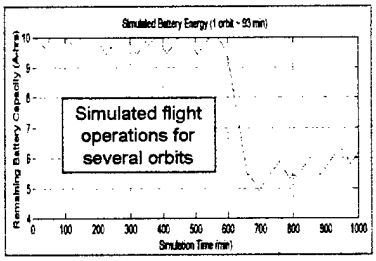
Solar cell data
Design criteria

Expected Power Output

Number of Cells per String	8.0	cells
Realized Voltage	18.5	V
Solar Cell Area Per String	168.0	cm2
Required String Area (w/ Packing)	240.0	cm2
Panel Area	1837.1	cm2
Number of Strings per Panel	7.0	strings
String Power	4845.1	mW
Total Panel Current	2038.0	mA
Total Panel Power Output	33.9	W
Calculated efficiency	20.6%	
Time-Average Output	23.7	W
Time-Average Supply to Bus	19.0	W

Panel supply current
Time average power

Design Simulation



Refinements in progress

Simulation thus far verifies adequate power supply for planned flight operations

Spacecraft Test Port Interface

- Provides terminals to charge batteries after integration
- Provides inhibit bypass, verification, and reset during test and integration
- Allows external [DB Connector Required] to the spacecraft
- DB25 Connector
- Allows final inhibit verification
- 10 inhibits with 2 pins each for latching + 1 common ground pin = 21 pins
- NiCd battery pack charging = 2 pins
- Total number of pins = 23 pins

Manufacturing

Power Board & Inhibits Board

- The Printed Circuit Boards (PCB) for the Electric Power Subsystem will be manufactured by Advanced Circuits, Inc. according to our design
- Populating the PCB
  - Each component will be soldered in place one-by-one in an orderly fashion following the board design layout

Battery Box

- Machine aluminum box to design dimensions
- Attach pressure relief valve to completed box
- Install fiberglass and Teflon spacer material
- Place NiCd battery pack into box and attach DB9 connector for interfacing with the electronics board

Testing & Integration

Power Board

- Connection continuity tests during board population procedure
- Board circuitry testing of:
  - Voltage regulator operation: measure outputs vs. inputs
  - Current sensor outputs: verify with voltmeter measurements
  - Dallas AD converter outputs: verify with voltmeter measurements
  - Simulate inhibit closing by connecting header pins
  - DB9 connections and pin outs

Inhibits Board

- Connection continuity tests during board population procedure
- Manually open and close inhibits and perform continuity tests for each inhibit
  - Test using the header pins used to interface with the Power Board
  - Test using the STPI DB25 connector
  - Test using the MSDS DB15 connectors (for T1 and T2)

Testing & Integration

Power & Inhibits Boards

- Integrate the Inhibits Board with the Power Board
  - Verify header pin connection

Battery Box

- Measure physical dimensions and confirm size
- Verify mounting hole locations and integrate with Orion structure
- Box interior:
  - Proper placement of fiberglass material
  - Proper seal at relief valve-to-box interface
  - Proper seal of completed battery box
- Verify mounting hole locations and integrate with Orion structure
- Integrate with Power Board
  - test for voltages (unregulated 14V and regulated 5V)

Testing & Integration

Solar Cells

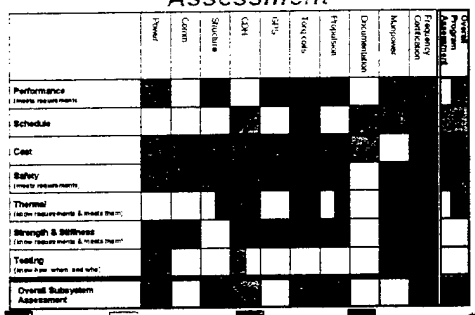
- Connect with electronics board
  - Verify proper connections
  - Observe outputs on current sensors
  - Check for the unregulated 14V and regulated 5V lines

Full Subsystem

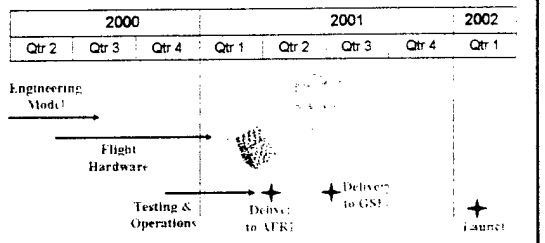
- Test inhibits through the STPI
  - Open and close inhibits
  - Check for continuity across each inhibit
  - Check for the unregulated 14V and regulated 5V lines
  - Check that the Propulsion Subsystem is inhibited per design
- Test inhibits through the MSDS connectors
- Connect various subsystems individually and observe operation of each subsystem
- Full system integration and observe operation of Orion

Orion Program Risk Assessment

Risk Assessment



Project Schedule



Nanosat One Critical Design Review

Principal Investigators:
Prof. Jonathan How
Prof. Christopher Kitts
Prof. Robert Twiggs

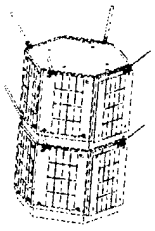
Emerald Structures and Mechanisms Subsystem

Design Summary

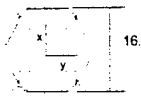
- Structure
  - Heritage SSDL design modified to meet 100Hz natural frequency requirements
- 3 Major mechanisms
  - Drag panel actuation mechanism
  - VLF antenna deployment and retention mechanism
  - Lightband intersatellite separation system
- Lightband designed by Planetary Systems

Structural Design

- Heritage SSDL Design
- Aluminum Honeycomb Hex Plates & Side Panels
  - 5052 Grade Aluminum (face skins)
  - 3003 Grade Aluminum (core)
- Longerons
  - 303 Stainless Steel 10-32 All-Thread
- Spacers and L-brackets
  - 6061T6 Aluminum
- Prototype structure with mass simulators tested to 11G's in random vibration with no damage



Structure



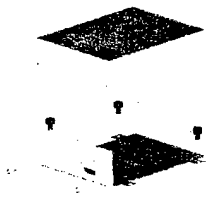
	CGx	CGy	CGz	Mass
Chromium	-.0006 m (-.0250 in)	-.0013 m (-.0493 in)	.1217 m (4.793 in)	13.46 kg (29.612 lb)
Beryl	-.0006 m (-.0250 in)	-.0013 m (-.0493 in)	.1217 m (4.793 in)	13.30 kg (29.26 lb)
Total Stack	-.0003 m (-.012 in)	-.0006 m (-.0246 in)	.3212 m (12.646 in)	26.76 kg (58.68 lb)

Internal Layout

- Layout design considerations
  - Ease of assembly/integration, testing
  - Simple wire harness
  - Minimal noise
  - Standardized layout between Beryl and Chromium
  - Fewer internal hexagon trays
  - Subsystem placement to place the CG in the center of the stack – will be adjusted with small balance masses

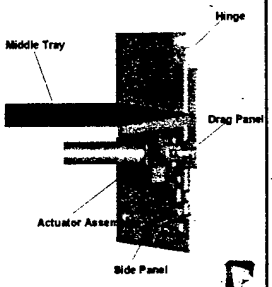
Subsystem/Experiment Box

- 1/32" Sheet Aluminum
- Modular Design
- Non-Fracture critical/Contained Part



Drag Panel Mechanism

- Driven by linear actuator system
  - TS Products dc-motor/lead screw driven actuator
  - Actuator mounted on swivel joint for necessary degrees of freedom for panel
- Mounted to middle tray

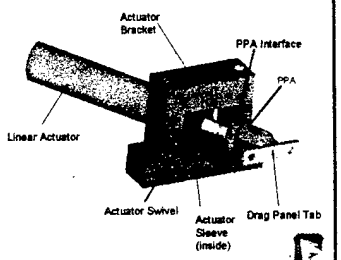


Drag Panel Mechanism

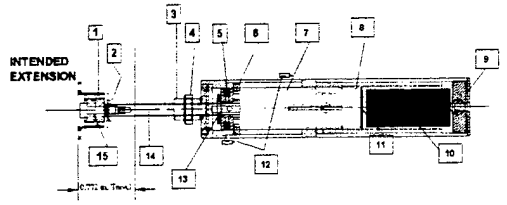
- Lead screw of each actuator is shortened to limit the maximum deployed width of the panels to 25.4 inches
- No contact with SHELS possible
- Panels extended .5 in. above and below edges of satellite to maintain 50% increase in ballistic coefficient when fully deployed
- Accidental drag panel deployment does not constitute a hazard

Actuator Bracket

- Bracket
  - Al 6061
- Swivel
  - AL 6061
- PPA
  - AL 6061
- Drag Panel Tab
  - Al 6061
- Sleeve
  - Delrin



Drag Panel Actuator Components

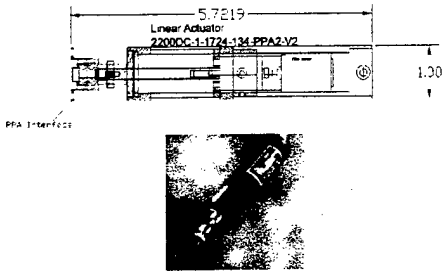


1 – Push/Pull Adapter
2 – REV Cushion
3 – Nose Mounting
4 – Mounting Nut
5 – Magnet
6 – Key
7 – Planetary Gear
8 – DC Motor
9 – Endcap
10 – Cable Coil Region
11 – Cable Scraper
12 – Travel Sensors (located in housing)
13 – Gear Output Shaft
14 – Lead Screw
15 – Ball Bearings

Actuator Description

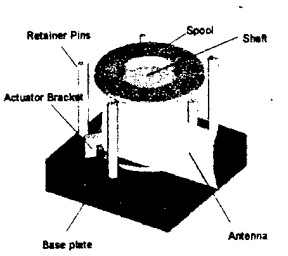
8	Motor	The motor shaft has a gear bonded onto the end using SM2216 epoxy. This gear then rolls into the planetary gear set
7	Planetary Gear	The motor housing and planetary gear housing are bonded together with SM2216 epoxy
13	Gear Output Shaft	The cylindrical output shaft with flat edge fits into a cylindrical cavity with a tolerance of +.001", -.005". There is a threaded hole in the lead screw into which a 0-80x1/16 set screw screws into. A cylindrical shaft on the end of the set screw fits into a hole on the output shaft. Both of these interfaces are also bonded using SM2216 epoxy. (see slide 6 & 7 for details)
5	Magnet	There are two magnets one on each side of the drive screw. When the drive screw is it's either intended retracted or extended position the magnets line up with sensors that are mounted in the actuator housing. The sensors serve as a check on the deployment of the drag panels. They are to determine when the actuator has reached its intended end of travel so the motor may shut off appropriately.
6	Key	Double-key holds the gearhead from rotating and prevents choking scenarios created by single-bobbed designs. Key runs through keyway in actuator housing
3	Nose Mounting	Stationary nut for driveshaft, driveshaft mates with interior threads and protrudes as it rotates
4	Mounting Nut	Nut secures the actuator onto its actuator sleeve
15	Ball Bearings	Allow push/pull adapter to rotate independently of drive screw

Fully Retracted Actuator

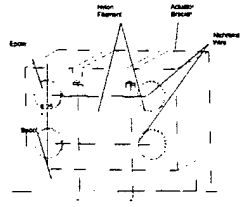


VLF Antenna Mechanism

- Stores and release 3m VLF antenna
- One mechanism on each nanosat
- Antenna made of uncoated, pre-curved steel tape
- Constrained by 2 nylon filaments



VLF Antenna Mechanism



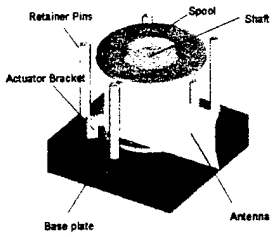
- Nichrome wire secured with epoxy
- Optical sensor detects deployment
- All electronics inhibited by the EPS

VLF Antenna Mechanism

- Each nylon filament tied in a loop with a blood knot
- Each flight know to be proof tested to 2.5 times maximum load
- Mechanism actuated by passing current through a nichrome wire in contact with both filaments
- Redundant strands of nichrome wire

Materials

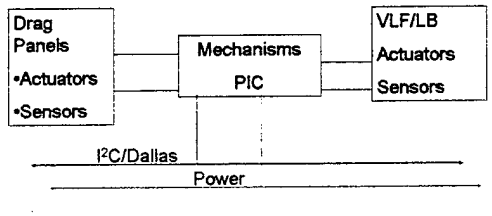
- VLF mechanism
  - Spool – Al 6061
  - Shaft – Delrin
  - Retainer Pins – Delrin
  - Actuator Bracket - Delrin
  - Antenna – Spring Steel Stanley Tape Measure



Supporting Electronics

- Drag Panel Sensors
  - Hall Effect: Fully Deployed
  - Hall Effect: Fully Retracted
  - Redundancy: Current Sensor
- Lightband/VLF Sensors
  - Micro-switches: Deployment Confirmation
  - Optical Sensor: Deployment Confirmation
  - Redundancy: Extra micro-switch on LB

Electronics Block Diagram



Fracture Control Classification

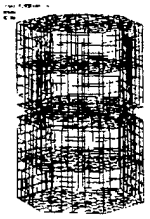
Component	Classification
AL Honeycomb Composite	Fracture critical composite/bonded structure
Linear Actuator	Fracture critical component
VLF nylon retention system	Fracture critical composite/bonded structure
Fasteners, L-brackets, Longerons, Spacers	Non Fracture Critical Low Risk

Structural Design Analysis

- FEA to determine structural design
  - Ideas v.7 FEM package
- Approach
  - Match previous vibe tests of engineering model
  - Update satellite connection to model Lightband
  - Test various design changes to increase frequency

Structural Analysis

- Building block solutions to verify with test
  - Fix middle plate to side panels with L-brackets
  - Add additional longeron(s)
  - Tie side panels together with angle bracket



Design Analysis

- Strength analysis of drag panel in deployed configuration
- Test verified analysis to show adequate strength margin in nylon line in VLF mechanism
- Thermal IDEAS TMG model for on-orbit analysis
- Strength analysis and test of insert pullouts

Thermal Controls

- Passive thermal control
  - Insulation blankets
  - Thermal tape
  - Cooling through radiation from body panels
  - Heating through power dissipation
- IDEAS thermal model for analysis

Temperature Limits

Acceptance Levels for Operation

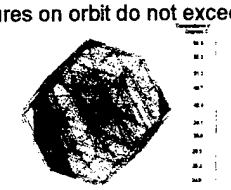
Sub-System	Low Temp. (C)	High Temp. (C)
GPS	-40	85
CMT	0	50
Distributed Computing	0	50
VLF Experiment	-25	85
COMM - Receivers	10	60
COMM - Transmitters	10	60
C&DH - SOFC	0	85
C&DH - Modem	-20	60
Batteries	-30	60

Qualification Levels

Sub-System	Low Temp. (C)	High Temp. (C)
GPS	-40	85
CMT	-20	85
Distributed Computing	-40	85
VLF Experiment	-40	85
COMM - Receivers	-40	85
COMM - Transmitters	-40	85
C&DH - SOFC	-40	85
C&DH - Modem	-40	85
Batteries	-30	60

Thermal Analysis

- FEM results
  - Free floating nanosat snapshot
  - Temperatures on orbit do not exceed limits



Manufacture

- Verifiable materials: certifications of compliance
- Instruments to be calibrated prior to use
- Manufacturing to be done under strict configuration management
  - Part drawings accompanied by manufacturing procedure and guidelines
  - Progress checks along manufacturing procedure to be done by second party
  - Final part verified by systems engineer

Assembly

- All fasteners supplied by GSFC
- Assemble according to procedure
- Assemble and store in clean environment
- Controlled access to flight hardware

Test

- Stack Level
  - Random Vibration
  - Frequency Characterization
  - Sine Burst
  - Thermal Vac Test
- Component Level
  - Proof test every flight knot for VLF mechanism to 2.5 times calculated dynamic load
- Fracture Critical Components
  - Proof Test to no less than 120% of limit load
  - Procedures to prevent damage from handling or final assembly
  - Manufacturer Certification
  - Create Test Articles

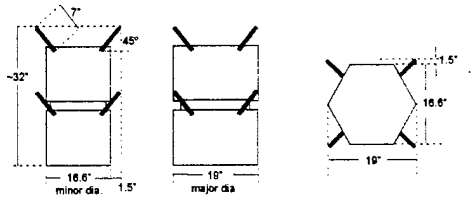
Ground Operations

- Drag panels may be tested on the ground via the STPI or by being commanded through an air link
- No other ground operations

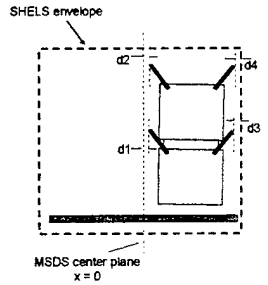
Requirements Fulfillment

- AFRL Requirements
  - Analysis shows that the structure will exceed 100 Hz in natural frequency
  - All separation system hole patterns conform to Lightband standard
  - RFDW approved for antenna exceeding the MSDS envelope
- Safety Requirements
  - VLF and drag panel mechanisms approved

Emerald Envelope



Emerald Envelope



Antennas fit within the SHELS envelope

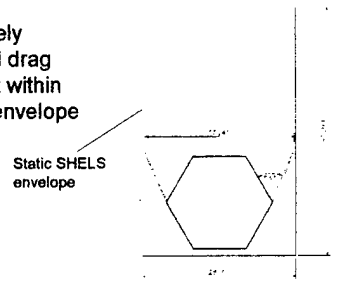
d1 = 0.342"

d2 = 0.952"

d3 = 1.06"

d4 = 0.45"

These dimensions approved by AFRL via RFDW

Emerald Envelope

- Completely deployed drag panels fit within SHELS envelope